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Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants, Part 2

Tetra Tech, Inc,
Lafayette, CA

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New technical developments in the field of water quality assessment and a reordering of water quality priorities prompted a revision of Water Quality Assessment: A Screening Methodology for Nondesignated 208 Areas (EPA-600/9-77-023). The utility of the revised manual is enhanced by the inclusion of information on the accumulation, transport, and fate of toxic chemicals in the environment. The new subtitle--A Screening Procedure for Toxic and Conventional Pollutants--reflects the added data.

Applying the manual's simple techniques, the user is now capable of assessing the loading and fate of conventional pollutants (temperature, biochemical oxygen demand-dissolved oxygen, nutrients, and sediments) and toxic pollutants (from the U.S. EPA list of priority pollutants) in streams, impoundments, and estuaries. The techniques are readily programmed on hand-held calculators. Most of the data required for using these procedures are contained in the manual.

Because of its size, the manual has been divided into three parts. Part 1 contains the introduction and chapters on the aquatic fate of toxic organic substances, waste load calculations, and the assessment of water quality parameters in rivers and streams. Part 2 continues with chapters on the assessment of impoundments and estuaries and appendices A,B,C,E,F,G, and H. Appendix D is provided in the third part.

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A Screening Procedure for Toxic and Conventional Pollutants

Part 2

by

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TABLE OF CONTENTS

PART 2

Page

DISCLAIMER ii

ABSTRACT iii

LIST OF FIGURES (PART 2) vi

LIST OF TABLES (PART 2) x

CHAPTER

5 IMPOUNDMENTS 1

- 5.1 Introduction 1
- 5.2 Impoundment Stratification 3
- 5.3 Sediment Accumulation 24
- 5.4 Eutrophication and Control 65
- 5.5 Impoundment Dissolved Oxygen 92
- 5.6 Toxic Chemical Substances 128
- 5.7 Application of Methods and Example Problem 140
- References for Chapter 5 185
- Glossary of Terms 187

6 ESTUARIES 191

- 6.1 Introduction 191
- 6.2 Estuarine Classification 207
- 6.3 Flushing Time Calculations 222
- 6.4 Far Field Approach to Pollutant Distribution in Estuaries 251
- 6.5 Pollutant Distribution following Discharge from a Marine Outfall 314
- 6.6 Thermal Pollution 367
- 6.7 Turbidity 379
- 6.8 Sedimentation 390
- References for Chapter 6 408

APPENDICES

- A Monthly Distribution of Rainfall Erosivity Factor R A-1
- B Methods for Predicting Soil Erodibility Index K B-1
- C Stream and River Data C-1
- D Impoundment Thermal Profiles D-1

APPENDICES (continued)

		Page
E	Modeling Thermal Stratification in Impoundments	E-1
F	Reservoir Sediment Deposition Surveys	F-1
G	Initial Dilution Tables	G-1
H	Equivalents of Commonly Used Units of Measurement	H-1

LIST OF FIGURES

PART 2

Figure | | Page
V-1 Water Density as a Function of Temperature and Dissolved Solids Concentration 4

V-2 Water Flowing into an Impoundment Tends to Migrate toward a Region of Similar Density 5

V-3 Annual Cycle of Thermal Stratification and Overturn in an Impoundment 6

V-4 Thermal Profile Plots Used in Example V-1 19

V-5 Thermal Profile Plots Appropriate for use in Example V-2 23

V-6 Sediment Rating Curve Showing Suspended Sediment Discharge as a Function of Flow 27

V-7 Relationship between the Percentage of Inflow-Transported Sediment Retained within an Impoundment and Ratio of Capicity to Inflow 29

V-8 Plot of C/R and CR^2 Versus R 34

V-9 Drag Coefficient (C) as Function of Reynold's Number (R) and Particle Shape 35

V-10 Schematic Representation of Hindered Settling of Particles in Fluid Column 36

V-11 Velocity Correction Factor for Hindered Settling 38

V-12 Upper and Lower Lakes and Environs, Long Island, New York 43

V-13 Impoundment Configurations Affecting Sedimentation 47

V-14 Kellis Pond and Surrounding Region, Long Island, New York 50

V-15 Hypothetical Depth Profiles for Kellis Pond 51

V-16 Hypothetical Flow Pattern in Kellis Pond 52

Figure Page

V-17 Hypothetical Depth Profiles for Kellis Pond Not Showing Significant Shoaling 53

V-18 Lake Owyhee and Environs 55

V-19 New Millpond and Environs. New Millpond is Subdivided for Purposes of Estimating Sedimentation in Regions A, B, and C 56

V-20 Significance of Depth Measures D, D^1 , and D^{11} , and the Assumed Sedimentation Pattern 59

V-21 Settling Velocity for Spherical Particles 60

V-22 Nomograph for Estimating Sediment Trap Efficiency 61

V-23 Formulations for Evaluating Management Options for Pollutants in Lakes and Reservoirs 70

V-24 US OECD Data Applied to Vollenweider (1976) Phosphorus Loading and Mean Depth/Hydraulic Residence Time Relationship 72

V-25 Relationship between Summer Chlorophyll and Spring Phosphorus 79

V-26 Maximal Primary Productivity as a Function of Phosphate Concentration 80

V-27 Conceptualization of Phosphorus Budget Modeling 85

V-28 Typical Patterns of Dissolved Oxygen in Hyrum Reservoir 93

V-29 Geometric Representation of a Stratified Impoundment 96

V-30 Quality and Ecologic Relationships 97

V-31 Rate of BOD Exertion at Different Temperatures Showing the First and Second Deoxygenation Stages 102

V-32 Quiet Lake and Environs 114

V-33 Thermal Profile Plots for Use in Quiet Lake Example 122

V-34 Nomograph for Estimating Sediment Trap Efficiency 141

V-35 Generalized Schematic of Lake Computations 147

V-36 The Occoquan River Basin 148

V-37 Thermal Profile Plots for Occoquan Reservoir 152

Figure		Page
V-38	Summary of Reservoir Sedimentation Surveys Made in the United States through 1970	155
V-39	Dissolved Oxygen Depletion Versus Time in the Occoquan Reservoir	180
VI-1	Typical Main Channel Salinity and Velocity for Stratified Estuaries	196
VI-2	Typical Main Channel Salinity and Velocity Profiles for Well Mixed Estuaries	197
VI-3	Typical Main Channel Salinity and Velocity Profiles for Partially Mixed Estuaries	199
VI-4	Estuarine Dimensional Definition	201
VI-5	Suggested Procedure to Predict Estuarine Water Quality	206
VI-6	Estuarine Circulation-Stratification Diagram	209
VI-7	Examples of Estuarine Classification Plots	209
VI-8	Circulation and Stratification Parameter Diagram	212
VI-9	The Stuart Estuary	214
VI-10	Stuart Estuary Data for Classification Calculations	215
VI-11	Estuarine Circulation-Stratification Diagram	218
VI-12	Alsea Estuary Seasonal Salinity Variations	220
VI-13	Estuary Cross-Section for Tidal Prism Calculations	223
VI-14	Patuxent Estuary Salinity Profile and Segmentation Scheme Used in Flushing Time Calculations	237
VI-15	Hypothetical Two-Branched Estuary	241
VI-16	Cumulative Upstream Water Volume, Fox Mill Run Estuary	246
VI-17	River-Borne Pollutant Concentration for One Tidal Cycle	259
VI-18	Alsea Estuary River-Borne Conservative Pollutant Concentration	263
VI-19	Pollutant Concentration form an Estuarine Outfall	265
VI-20	Hypothetical Concentration of Total Nitrogen in Patuxent Estuary	271

Figure Page

VI-21 Relative Depletions of Three Pollutants Entering the Fox Mill Run Estuary, Virginia 281

VI-22 Additive Effect of Multiple Waste Load Additions 283

VI-23 Dissolved Oxygen Saturation as a Function of Temperature and Salinity 296

VI-24 Predicted Dissolved Oxygen Profile in James River 298

VI-25 Definition Sketch for Pritchard's Two-Dimensional Box Model 302

VI-26 Patuxent Estuary Model Segmentation 311

VI-27 Waste Field Generated by Marine Outfall 316

VI-28 Example Output of MERGE - Case 1 326

VI-29 Example Output of MERGE - Case 2 327

VI-30 Schematic of Plume Behavior Predicted by MERGE in the Present Usage 332

VI-31 Cross Diffuser Merging 336

VI-32 Plan View of Spreading Sewage Field 355

VI-33 Outfall Location, Shellfish Harvesting Area, and Environs 360

VI-34 Dissolved Oxygen Depletions Versus Travel Time 366

VI-35 Centerline Dilution of Round Buoyant Jet in Stagnant Uniform Environment 377

VI-36 Mean Suspended Solids in San Francisco Bay 381

VI-37 Water Quality Profile of Selected Parameters Near a Municipal Outfall in Puget Sound, Washington 386

VI-38 Sediment Movement in San Francisco Bay System 396

VI-39 Idealized Estuarine Sedimentation 397

VI-40 Particle Diameter Versus Settling Fall per Tidal Cycle (12.3 hrs) under Quiescent Conditions (Spheres with Density 2.0 g/cm^3) 402

VI-41 Estuarine Null Zone Identification 405

LIST OF TABLES

PART 2

Table		Page
V-1	Parameter Values Used in Generation of Thermal Gradient Plots (Appendix D)	10
V-2	Temperature, Cloud Cover, and Dew Point Data for the Ten Geographic Locales Used to Develop Thermal Stratification (Appendix D)	12
V-3	Limpid Lake Characteristics	18
V-4	Physical Characteristics of Lake Smith	20
V-5	Comparison of Monthly Climatologic Data for Shreveport, Louisiana, and Atlanta, Georgia	21
V-6	Hypothetical Physical Characteristics of Upper Lake, Brookhaven, Suffolk County, New York	44
V-7	Hypothetical Physical Characteristics of Lower Lake, Brookhaven, Suffolk County, New York	46
V-8	Hypothetical Physical Characteristics of Lower Lake, Brookhaven, Suffolk County, New York (Assuming an Epilimnion Depth of 10 ft)	48
V-9	Classification of Lake Restoration Techniques	83
V-10	Oxygen Demand of Bottom Deposits	104
V-11	Solubility of Oxygen in Water	106
V-12	Characteristics of Quiet Lake	115
V-13	Water Quality and Flow Data for Tributaries to Quiet Lake. Data Represent Mean Figures for 1970-1975	115
V-14	Precipitation and Runoff Data for Quiet Watershed. Values Are Means of Data Collected from Both Stations.	118
V-15	DO Sag Curve for Quiet Lake Hypolimnion	127
V-16	Significant Processes Affecting Toxic Substances in Aquatic Ecosystems	129

Table		Page
V-17	Comparison of Modeled Thermal Profiles to Observed Temperatures in Occoquan Reservoir	154
V-18	Annual Sediment and Pollutant Loads in Occoquan Watershed	157
V-19	Sediment Loaded into Lake Jackson	158
V-20	Calculation Format for Determining Sediment Accumulation in Reservoirs	159
V-21	Particle Sizes in Penn Silt Load	160
V-22	Calculation Format for Determining Sediment Accumulation in Reservoirs	161
V-23	Sewage Treatment Plant Pollutant Loads in Bull Run Sub-Basin	167
V-24	Calculated Annual Pollutant Loads to Occoquan Reservoir	168
V-25	Observed Annual Pollutant Loads to Occoquan Reservoir	170
V-26	Calculated and Observed Mean Annual Pollutant Concentrarions in Occoquan Reservoir	172
VI-1	Summary of Methodology for Estuarine Water Quality Assessment	205
VI-2	Tidal Prisms for Some U.S. Estuaries	224
VI-3	Sample Calculation Table for Calculation of Flushing Time by Segmented Fraction of Freshwater Method	234
VI-4	Patuxent Estuary Segment Characteristics for Flushing Time Calculations	236
VI-5	Flushing Time for Patuxent Estuary	239
VI-6	Sample Calculation Table for Estuarine Flushing Time by the Modified Tidal Prism Method	245
VI-7	Data and Flushing Time Calculations for Fox Mill Run Estuary	249
VI-8	Pollutant Distribution in the Patuxent River	257
VI-9	Incremental Total Nitrogen in Patuxent River (See Problem VI-5)	258
VI-10	Sample Calculation Table for Distribution of a Locally Discharged Conservative Pollutant fy the Fraction of Freshwater Method	267
VI-11	Nitrogen Concentration in Patuxent Estuary Based on Local Discharge	269

Table		Page
VI-12	Typical Values for Decay Reaction Rates 'k'	273
VI-13	Sample Calculation Table for Distribution of a Locally Discharged Non-conservative Pollutant by the Modified Tidal Prism Method	277
VI-14	Salinity and CBOD Calculations for Fox Mill Run Estuary	279
VI-15	Distribution of Total Nitrogen in the Patuxent Estuary due to Two Sources of Nitrogen	286
VI-16	Tidally Averaged Dispersion Coefficients for Selected Estuaries	289
VI-17	Tidally Averaged Dispersion Coefficients	290
VI-18	Salinity and Pollutant Distribution in Patuxent Estuary under Low Flow Conditions	310
VI-19a	Water Densities Calculated using the Density Subroutine Found in MERGE	320
VI-19b	Water Densities Calculated using the Density Subroutine Found in MERGE	321
VI-19c	Water Densities Calculated using the Density Subroutine Found in MERGE	322
VI-20	Plume Variables, Units, and Similarity Conditions	325
VI-21	Values of Equilibrium Constants and Ion Product of Water as a Function of Temperature for Freshwater and Salt Water	343
VI-22	Estimated pH Values after Initial Dilution	346
VI-23	Dissolved Oxygen Profile in Commencement Bay, Washington	351
VI-24	Subsequent Dilutions for Various Field Widths and Travel Times	358
VI-25	Data Needed for Estuary Thermal Screening	370
VI-26	Maximum Allowable Channel Velocity to Avoid Bed Scour	393
VI-27	Sediment Particle Size Ranges	399
VI-28	Rate of Fall in Water of Spheres of Varying Radii and Constant Density of 2 as Calculated by Stokes' Law	400

CHAPTER 5

IMPOUNDMENTS

5.1 INTRODUCTION

This chapter contains several methods for assessing water quality and physical conditions in impoundments. The general topics covered are sediment accumulation, thermal stratification, DO-BOD, euthrophication, and toxicant concentrations. These topics cover the major water problems likely to occur in impoundments. The methods developed are easy to use and require readily obtainable data. Because the methods depend upon a number of simplifying assumptions, estimates should be taken only as a guide pending further analysis. Also, since pollutant inputs are dependent on previous calculations, familiarity with the methods in previous chapters will be very helpful and expand understanding of the various processes.

Some of the techniques are more mechanistic and reliable than others. For example, the thermal stratification technique is based upon output of a calibrated and validated hydrothermal model. The model has been shown to be a good one, and to the extent that physical conditions in the studied impoundments resemble those of the model, results should be very reliable. On the other hand, the methods for predicting eutrophication are empirical and based upon correlations between historical water quality conditions and algal productivity in a number of lakes and reservoirs. Because algal blooms are sensitive to environmental factors and the presence of toxicants and factors other than those involved in the estimation methods, the methods for predicting eutrophication will occasionally be inapplicable. Since the planner may not be able to assess applicability in specific cases, results may occasionally be inaccurate.

In using the techniques to be presented, it is important to apply good "engineering judgment" particularly where sequential application of methods is likely to result in cumulative errors. Such would be the case, for example, in evaluating impoundment hypolimnion DO problems resulting from algal blooms. If methods presented below are used to evaluate hypolimnion DO, the planner should determine when stratification occurs, the magnitude of point and nonpoint source BOD loads, and algal productivity and settling rates. From all of this, he may then predict BOD and DO levels in the hypolimnion. Since each of these techniques has an error associated with it, the end result of the computation will have a significant error envelope and results must be interpreted accordingly. The best way to use any of the techniques is to assume a range of values for important coefficients in order to obtain a range of results within which the studied impoundment is likely to fall.

Although scientists and engineers are familiar with the metric system of units, planners, local interest groups, and the general public are more accustomed to the English system. Most morphometric data on lakes and impoundments are in English units. The conversion tables in Appendix H should be thoroughly familiar before using these techniques and users should be able to perform calculations in either system even though metric units are simpler to use. Also, dimensional analysis techniques using unit conversions are very helpful in performing the calculations.

The methods presented below are arranged in an order such that the planner should be able to use each if he has read preceding materials. The order of presentation is:

- Impoundment stratification (5.2)
- Sediment accumulation (5.3)
- Eutrophication (5.4)
- Impoundment dissolved oxygen (5.5)
- Fate of Priority Pollutants (Toxics)(5.6)

It is strongly recommended that all materials presented be read and examples worked prior to applying any of the methods. In this way a better perspective can be obtained on the kinds of problems covered and what can be done using hand calculations. A glossary of terms has been placed after the reference section so that equation terms can easily be checked.

The final section (5.7) is an example application to a selected site. This example allows the user to have an integrated view of an actual problem and application. Also "the goodness of fit" to measured results can be evaluated.

5.2 IMPOUNDMENT STRATIFICATION

5.2.1 Discussion

The density of water is strongly influenced by temperature and by the concentration of dissolved and suspended matter. Figure V-1 shows densities for water as a function of temperature and dissolved solids concentration (from Chen and Orlob, 1973).

Regardless of the reason for density differences, water of lowest density tends to move upward and reside on the surface of an impoundment while water of greatest density tends to sink. Inflowing water seeks an impoundment level containing water of the same density. Figure V-2 shows this effect schematically.

Where density gradients are very steep, mixing is inhibited. Thus, where the bottom water of an impoundment is significantly more dense than surface water, vertical mixing is likely to be unimportant. The fact that low density water tends to reside atop higher density water and that mixing is inhibited by steep gradients often results in impoundment stratification. Stratification, which is the establishment of distinct layers of different densities, tends to be enhanced by quiescent conditions. Conversely, any phenomenon encouraging mixing, such as wind stress, turbulence due to large inflows, or destabilizing changes in water temperature will tend to reduce or eliminate strata.

5.2.1.1 Annual Cycle in a Thermally Stratified Impoundment

Figure V-3 shows schematically the processes of thermal stratification and overturn which occur in many impoundments. Beginning at "a" in the figure (winter), cold water (at about $4^{o}C$) flows into the impoundment which may at this point be considered as fully mixed. There is no thermal

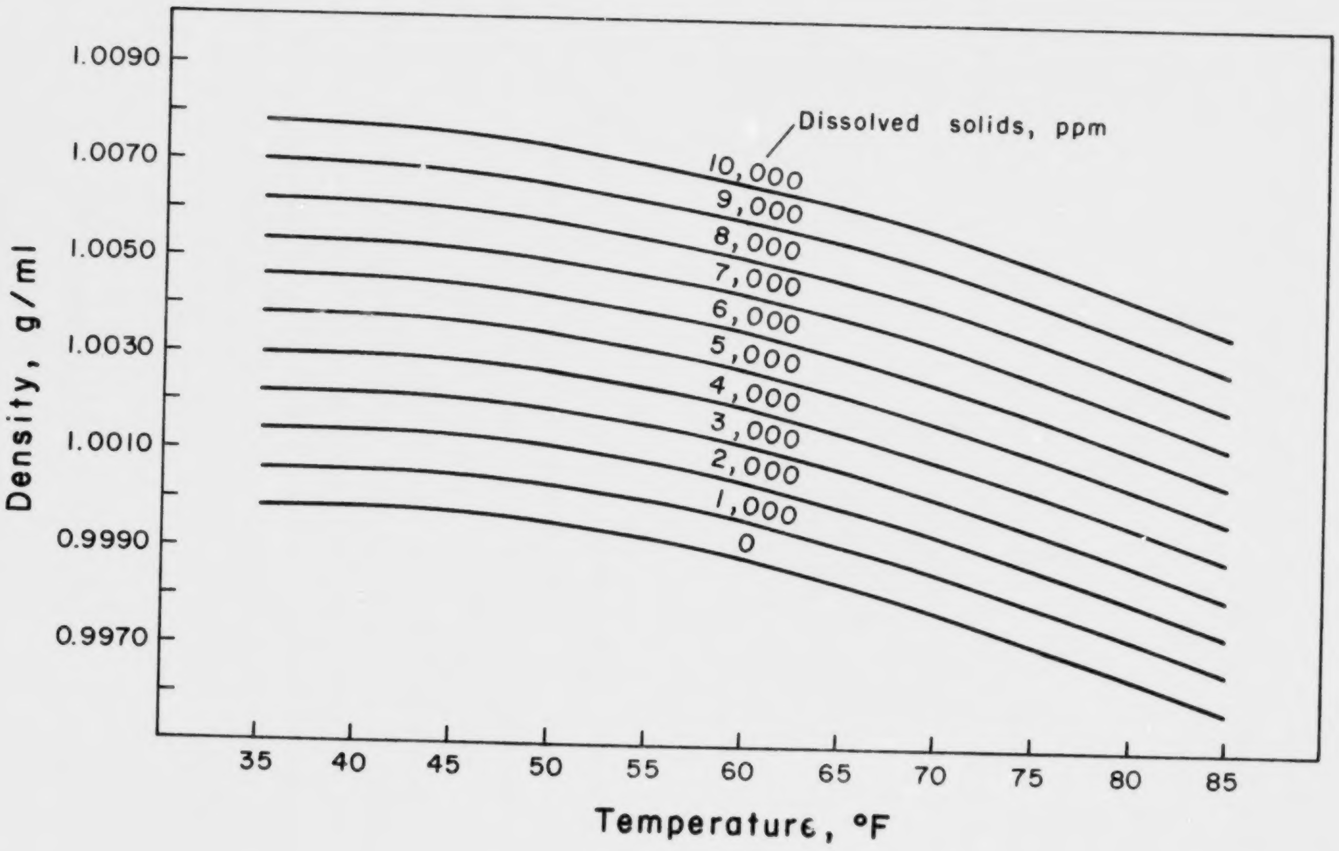


FIGURE V-1 WATER DENSITY AS A FUNCTION OF TEMPERATURE AND DISSOLVED SOLIDS CONCENTRATION (FROM CHEN AND ORLOB, 1973)

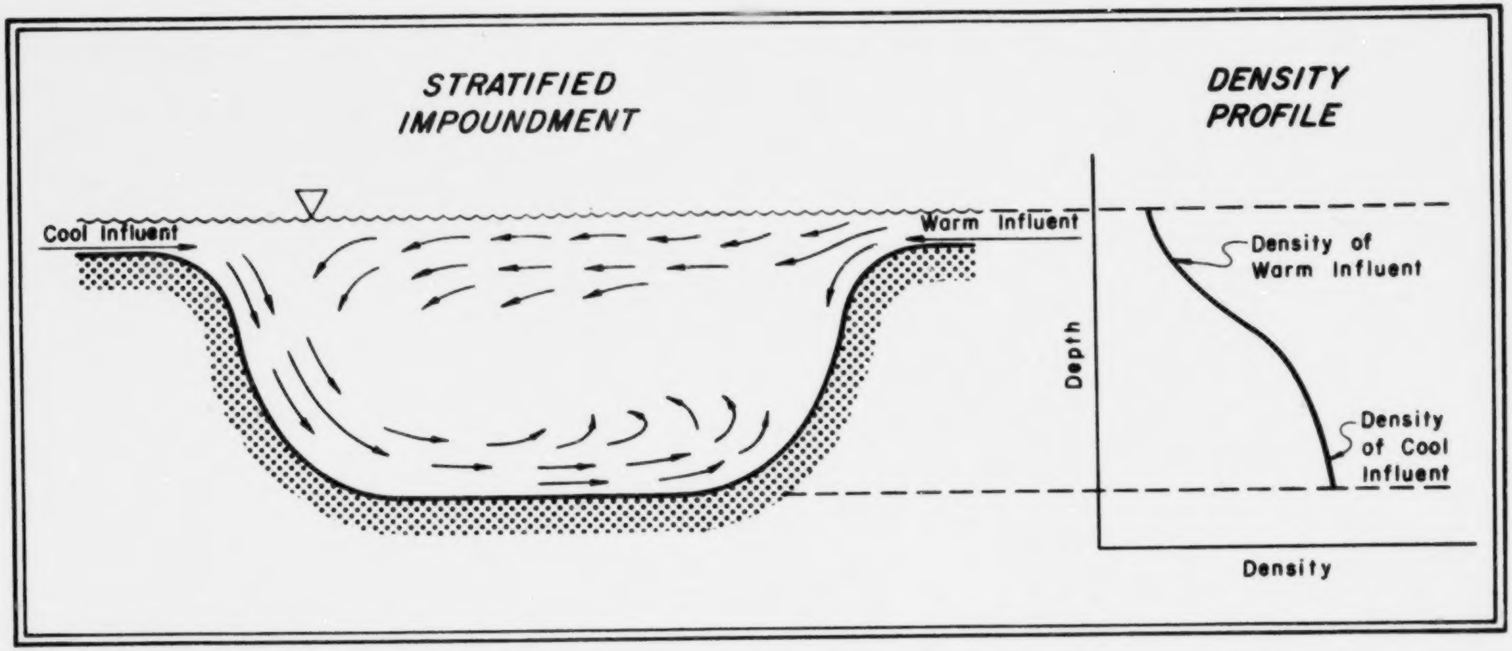


Figure V-2 Water Flowing into an Impoundment Tends to Migrate toward a Region of Similar Density

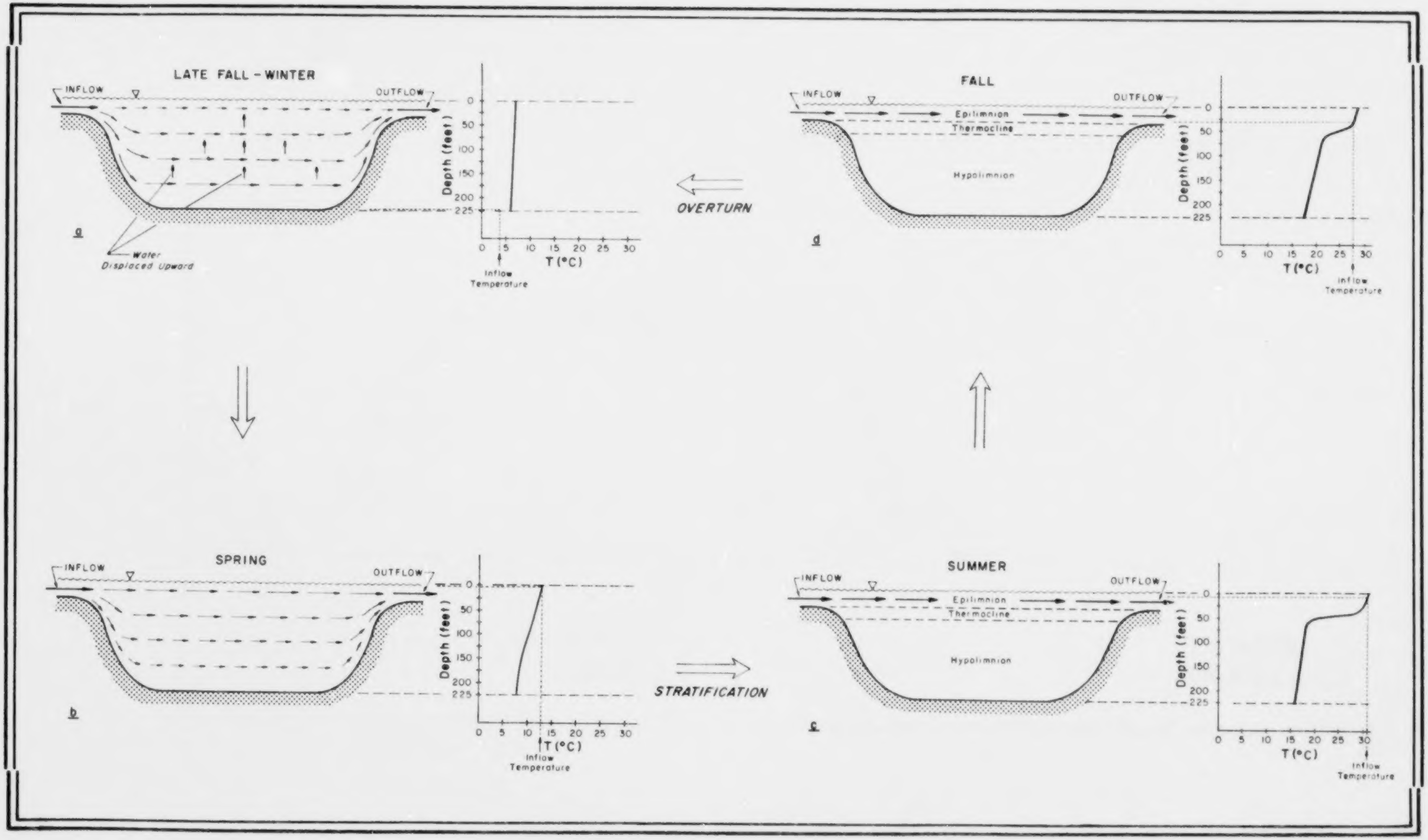


FIGURE V-3 ANNUAL CYCLE OF THERMAL STRATIFICATION AND OVERTURN IN AN IMPOUNDMENT

gradient over depth and the impoundment temperature is about 6 C. During spring ("b"), inflowing water is slightly warmer than that of the impoundment because of the exposure of the tributary stream to warmer air and increasingly intense sunlight. This trend continues during the summer ("c"), with tributary water being much warmer and less dense than the deep waters of the impoundment. At the same time, the surface water of the impoundment is directly heated by insolation. Since the warm water tends to stay on top of the impoundment, thermal strata form.

As fall approaches ("d"), day length decreases, air temperatures drop, and solar intensity decreases. The result is cooler inflows and a cooling trend in the surface of the impoundment. The bottom waters lag behind the surface in the rate of temperature change, and ultimately the surface may cool to the temperature of the bottom. Since continued increases in surface water density result in instability, the impoundment water mixes (overturns).

5.2.1.2 Monomictic and Dimictic Impoundments

The stratification and overturn processes described in Figure V-3 represent what occurs in a monomictic or single-overturn water body. Some impoundments, especially those north of 40^{o}N latitude and those at high elevation may undergo two periods of stratification and two overturns. Such impoundments are termed "dimictic." In addition to the summer stratification and resulting fall overturn, such impoundments stratify in late winter. This occurs because water is most dense near 4^{o}C, and bottom waters may be close to this temperature, while inflowing water is colder and less dense. As the surface goes below 4^{o}C, strata are established. With spring warming of the surface to 4^{o}C, wind induced mixing occurs.

5.2.1.3 Importance of Stratification

Stratification is likely to be the single most important phenomenon affecting water quality in many impoundments. Where stratification is absent, water mixes vertically, and net horizontal flow is significant to considerable depths. Since the water is mixed vertically, DO replenishment usually occurs even to the bottom and anoxic (literally "no oxygen") conditions are unlikely. Generally speaking, fully mixed impoundments do not have DO deficiency problems.

When stratification occurs, the situation is vastly different. Flow within the impoundment is essentially limited to the epilimnion (surface layer). Thus surface velocities are somewhat higher in an impoundment when stratified than when unstratified. Since vertical mixing is inhibited by stratification, reaeration of the hypolimnion (bottom layer) is virtually nonexistent. The thermocline (layer of steep thermal gradient between epilimnion and hypolimnion) is often at considerable depth. Accordingly, the euphotic (literally "good light") zone is likely to be limited to the epilimnion. Thus photosynthetic activity does not serve to reoxygenate the hypolimnion. The water that becomes the hypolimnion has some oxygen demand prior to the establishment of strata. Because bottom (benthic) matter exerts a further demand, and because some settling of particulate matter into the hypolimnion may occur, the DO level in the hypolimnion will gradually decrease over the period of stratification.

Anoxic conditions in the hypolimnion result in serious chemical and biological changes. Microbial activity leads to hydrogen sulfide (H_2S) evolution as well as formation of other highly toxic substances, and these may be harmful to indigenous biota.

It should be noted that the winter and spring strata and overturn are relatively unimportant here since the major concern is anoxic conditions in the hypolimnion in summer. Thus all impoundments will be considered as monomictic.

Strong stratification is also important in prediction of sedimentation rates and trap efficiency estimates. These topics are to be covered later.

5.2.2 Prediction of Thermal Stratification

Computation of impoundment heat influx is relatively straightforward, but prediction of thermal gradients is complicated by prevailing physical conditions, physical mixing phenomena, and impoundment geometry. Such factors as depth and shape of impoundment bottom, magnitude and configuration of inflows, and degree of shielding from the wind are much more difficult to quantify than insolation, back radiation, and still air evaporation rates. Since the parameters which are difficult to quantify are critical to predicting stratification characteristics, no attempt has been made to develop a simple calculation procedure. Instead, a tested model (Chen and Orlob, 1973; Lorenzen and Fast, 1976) has been subjected to a sensitivity analysis and the results plotted to show thermal profiles over depth and over time for some representative geometries and climatological conditions. The plots are presented in Appendix D.

The plots show the variation in temperature (^{o}C) with depth (meters). Temperature is used as an index of density. Engineering judgment about defining layers is based on the pattern of temperature with depth. If stratification takes place, the plot will show an upper layer of uniform or slightly declining temperature (epilimnion), an intermediate layer of sharply declinging temperature (thermocline), and a bottom layer (hypolimnion). A rule of thumb requires a temperature change of at least 1 C/meter to define the thermocline. However, this can be tempered by the observation of a well defined mixed layer.

To assess thermal stratification in an impoundment, it is necessary only to determine which of the sets of plots most closely approximates climatic and hydrologic conditions in the impoundment studied. Parameters which were varied to generate the plots and values used are shown in Table V-1.

TABLE V-1

PARAMETER VALUES USED IN GENERATION OF THERMAL GRADIENT PLOTS (APPENDIX D)

Parameter	Value
Geographic Locale	Atlanta, Georgia
	Billings, Montana
	Burlington, Vermont
	Flagstaff, Arizona
	Fresno, California
	Minneapolis, Minnesota
	Salt Lake City, Utah
	San Antonio, Texas
	Washington, D.C.
	Wichita, Kansas

Geometry	Depth (maximum, feet)	Surface Area ($feet^2$)	Volume ($feet^3$)
	20	8.28×10^6	7.66×10^7
	40	3.31×10^7	6.13×10^8
	75	1.16×10^8	4.04×10^9
	100	2.07×10^8	9.58×10^9
	200	8.28×10^8	7.66×10^{10}

Mean Hydraulic Residence Time	Days
	10
	30
	75
	250
	∞
Wind Mixing*	High
	Low

*See Appendix E.

Table V-2 shows the climatological conditions used to represent the geographic locales listed in Table V-1. For details of the simulation technique, see Appendix E.

5.2.2.1 Using the Thermal Plots

Application of the plots to assess stratification characteristics begins with determining reasonable values for the various parameters listed in Table V-1. For geographic locale, the user should determine whether the impoundment of interest is near one of the ten areas for which thermal plots have been generated. If so, then the set of plots for that area should be used. If the impoundment is not near one of the ten areas, then the user may obtain data for the parameters listed in Table V-2 (climatologic data) and then select the modeled locale which best matches the region of interest.

Next, the user must obtain geometric data for the impoundment. Again, if the impoundment of interest is like one for which plots have been generated, then that set should be used. If not, the user should bracket the studied impoundment. As an example, if the studied impoundment is 55 feet deep (maximum), with a surface area of about 4×10^7 feet^2, then the 40 and 75 foot deep impoundment plots should be used.

Mean hydraulic residence time (τ_w, years) may be estimated using the mean total inflow rate (Q, m^3/year) and the impoundment volume (V,m^3):

$$\tau_w = V/Q \tag{V-1}$$

Again, the sets of plots bracketing the value of τ_w should be examined. Where residence times are greater than 200 days, the residence time has little influence on stratification (as may be verified in Appendix D) and either the 200 day or infinite time plots may be used.

Finally, the wind mixing coefficient was used to generate plots for windy areas (high wind) and for very well protected areas (low wind). The

TABLE V-2

TEMPERATURE, CLOUD COVER, AND DEW POINT DATA FOR THE TEN GEOGRAPHIC LOCALES USED TO DEVEOP THERMAL STRATIFICATION PLOTS (APPENDIX D). SEE FOOT OF TABLE FOR NOTES.

	Temperature (^{O}F)			Dew Point (^{O}F)	Cloud Cover Fraction	Wind (MPH)
	Max.	Mean	Min.			
	Atlanta (Lat:33.8^{O}N, Long:84.4^{O}W)					
January	54	45	36	34	.63	11
February	57	47	37	34	.62	12
March	63	52	41	39	.61	12
April	72	61	50	48	.55	11
May	81	70	57	57	.55	9
June	87	77	66	65	.58	8
July	88	79	69	68	.63	8
August	88	78	68	67	.57	8
September	83	73	63	62	.53	8
October	74	63	52	51	.45	9
November	62	51	40	40	.51	10
December	53	44	35	34	.62	10
	*Billings (Lat:45.8^{O}N, Long:108.5^{O}W)					
January	27	18	9	11	.68	13
February	32	22	12	16	.68	12
March	38	27	16	20	.71	12
April	51	38	26	28	.70	12
May	60	47	34	38	.64	11
June	68	54	40	46	.60	11
July	79	63	46	48	.40	10
August	78	61	45	46	.42	10
September	67	52	37	38	.54	10
October	55	42	30	31	.56	11
November	38	29	20	22	.66	13
December	32	22	14	15	.66	13

TABLE V-2 - CONT.

	Temperature (°F)			Dew Point (°F)	Cloud Cover Fraction	Wind (MPH)
	Max.	Mean	Min.			
	Burlington (Lat:44.5°N, Lat:73.2°W)					
January	27	18	9	12	.72	10
February	29	19	10	12	.69	10
March	38	29	20	20	.66	10
April	53	43	33	32	.67	10
May	67	56	44	43	.67	9
June	54	66	77	54	.61	9
July	82	71	59	59	.58	8
August	80	68	57	58	.57	8
September	71	60	49	51	.60	8
October	59	49	39	40	.65	9
November	44	38	29	30	.79	10
December	31	23	15	17	.78	10
	Flagstaff (Lat:35.2°N, Long:111.3°W)					
January	40	27	14	14	.59	8
February	43	30	17	16	.49	9
March	50	36	22	17	.50	11
April	59	43	28	20	.49	12
May	68	51	34	22	.41	11
June	77	60	42	25	.24	11
July	81	66	50	43	.54	9
August	79	64	49	43	.53	9
September	75	59	42	35	.29	8
October	63	47	31	25	.31	8
November	51	36	21	20	.34	8
December	44	30	17	15	.44	7

TABLE V-2 CONT.

	Temperature (^{O}F) Max.	Mean	Min.	Dew Point (^{O}F)	Cloud Cover Fraction	Wind (MPH)
	Fresno (Lat:36.7^{O}N, Long:119.8^{O}W)					
January	55	46	37	38	.67	6
February	61	51	40	41	.61	6
March	68	55	42	41	.53	7
April	76	61	46	44	.44	7
May	85	68	52	45	.34	8
June	92	75	57	48	.19	8
July	100	81	63	51	.11	7
August	98	79	61	52	.11	6
September	92	74	56	51	.15	6
October	81	65	49	46	.28	5
November	68	54	40	42	.44	5
December	57	47	38	40	.70	5
	Minneapolis (Lat:45.0^{O}N, Long:93.3^{O}W)					
January	22	12	3	6	.65	11
February	26	16	5	10	.62	11
March	37	28	18	20	.67	12
April	56	45	33	32	.65	13
May	70	58	46	43	.64	12
June	79	67	56	55	.60	11
July	85	76	61	60	.49	9
August	82	71	59	59	.51	9
September	72	61	49	50	.51	10
October	60	48	37	40	.54	11
November	40	31	21	25	.69	12
December	27	18	9	13	.69	11

TABLE V-2 CONT.

	Temperature (°F)			Dew Point (°F)	Cloud Cover Fraction	Wind (MPH)
	Max.	Mean	Min.			
Salt Lake City (Lat:40.8°N, Long:111.9°W)						
January	37	27	18	20	.69	7
February	42	33	23	23	.70	8
March	51	40	30	26	.65	9
April	62	50	37	31	.61	9
May	72	58	45	36	.54	10
June	82	67	52	40	.42	9
July	92	76	61	44	.35	9
August	90	75	59	45	.34	10
September	80	65	50	38	.34	9
October	66	53	39	34	.43	9
November	49	38	28	28	.56	8
December	40	23	32	24	.69	7
San Antonio (Lat:29.4°N, Long:98.5°W)						
January	62	52	42	39	.64	9
February	66	55	45	42	.65	10
March	72	61	50	45	.63	10
April	79	68	58	55	.64	11
May	85	75	65	64	.62	10
June	92	82	72	68	.54	10
July	94	84	74	68	.50	10
August	94	84	73	67	.46	8
September	89	79	69	65	.49	8
October	82	71	60	56	.46	8
November	70	59	49	46	.54	9
December	65	42	54	41	.57	9

TABLE V-2 CONT.

	Temperature (°F)			Dew Point (°F)	Cloud Cover Fraction	Wind (MPH)
	Max.	Mean	Min.			
	Washington, D.C. (Lat:38.9°N, Long:77.0°W)					
January	44	37	30	25	.61	11
February	46	38	29	25	.56	11
March	54	45	36	29	.56	12
April	60	56	46	40	.54	11
May	76	66	56	52	.54	10
June	83	74	65	61	.51	10
July	87	78	69	65	.51	9
August	85	77	68	64	.51	8
September	79	70	61	59	.48	9
October	68	59	50	48	.47	9
November	57	48	39	36	.54	10
December	46	43	31	26	.58	10
	Wichita (Lat:37.7°N, Long:97.3°W)					
January	42	32	22	21	.50	12
February	47	36	26	25	.51	13
March	56	45	33	30	.52	15
April	68	57	45	41	.53	15
May	77	66	55	53	.53	13
June	88	77	65	62	.46	13
July	92	81	69	65	.39	12
August	93	81	69	53	.38	11
September	84	71	59	55	.39	12
October	72	60	48	43	.40	12
November	34	55	44	33	.44	13
December	45	36	27	25	.50	12

TABLE V-2 CONT.

Notes: Mean: Normal daily average temperature, °F.
Max.: Normal daily maximum temperature, °F.
Min.: Normal daily minimum temperature, °F.
Wind: Mean wind speed, MPH
Dew Point: Mean dew point temperature, °F.

*Complete data were not available for Billings. Tabulated data are actually a synthesis of available data for Billings, Montana and Yellowstone, Wyoming.

All data taken from Climatic Atlas of the U.S., 1974.

user must judge where his studied impoundment falls and interpolate in the plots accordingly (See Appendix D).

EXAMPLE V-1

Thermal Stratification

Suppose one wants to know the likelihood that hypothetical Limpid Lake is stratified during June. The first step is to compile the physical conditions for the lake in terms of the variables listed in Table V-1. Table V-3 shows how this might be done. Next, refer to the indexes provided in Appendix D to locate the plot set for conditions most similar to those of the studied impoundment. In this case, the Wichita plots for a 200-foot deep impoundment with no inflow and high mixing rate would be chosen (see Table V-3). Figure V-4 is a reproduction of the appropriate page from Appendix D.

TABLE V-3

LIMPID LAKE CHARACTERISTICS

Item	Limpid Lake	Available Plot
Location	Manhattan, Kansas	Wichita, Kansas
Depth, ft (maximum)	180	200
Volume, ft^3	6×10^{10}	7.66×10^{10}
Mean residence time (τ_w)	500 days	∞ (no inflow)
Mixing	high (windy)	high coefficient

According to the plots, Limpid Lake is likely to be strongly stratified in June. Distinct strata form in May and overturn probably occurs in December. During June, the epilimnion should extend down to a depth of about eight or ten feet, and the thermocline should extend down to

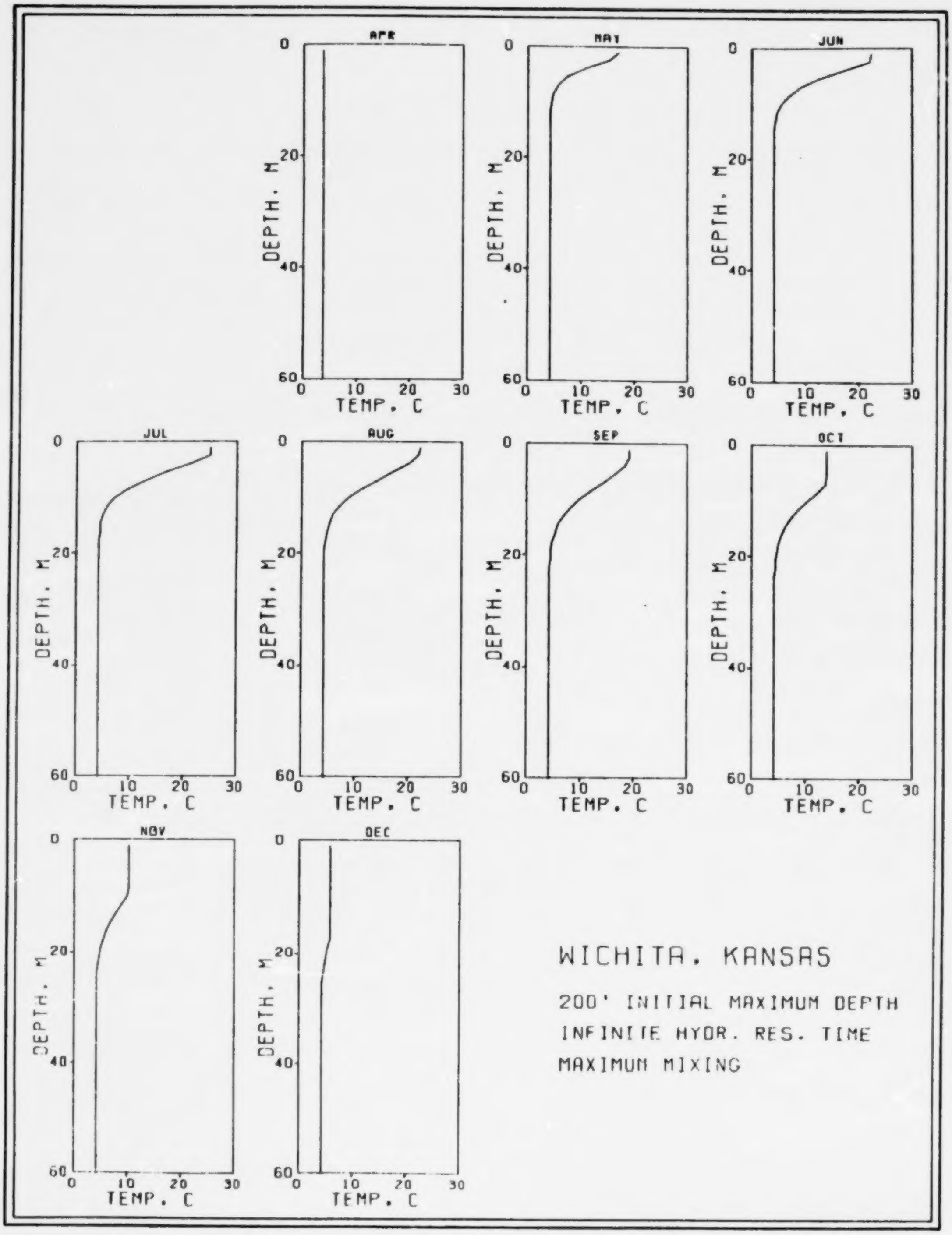


FIGURE V-4 THERMAL PROFILE PLOTS USED IN EXAMPLE V-1

about 30 feet. The gradient in the thermocline should be about 1°C per meter.

END OF EXAMPLE V-1

EXAMPLE V-2

Thermal Stratification

What are the stratification characteristics of Lake Smith?

The hypothetical lake is located east of Carthage, Texas, and Table V-4 shows its characteristics along with appropriate values for the thermal plots.

TABLE V-4

PHYSICAL CHARACTERISTICS OF LAKE SMITH

Item	Lake Smith	Plot Values
Location	15 miles east of Carthage Texas	-
Depth, ft (maximum)	23	20
Volume, ft^3	3×10^8	1.66×10^8
Mean residence time	250 days	∞
Mixing	low (low wind)	low mixing coefficient

From the available data for Lake Smith, it appears that plots for a 20-foot deep impoundment with no inflow and low mixing coefficient should give a good indication of the degree of summertime stratification. The one remaining problem is climate. Data for nearby Shreveport, Louisiana compare well with those of Atlanta (Table V-5), for which plots are provided in Appendix D, and latitudes are similar. Shreveport is somewhat warmer and insolation is higher, but this is a relatively uniform difference over the

TABLE V-5

COMPARISON OF MONTHLY CLIMATOLOGIC DATA FOR SHREVEPORT, LOUISIANA AND ATLANTA, GEORGIA DATA ARE PRESENTED AS SHREVEPORT/ATLANTA (CLIMATIC ATLAS OF THE U.S., 1974)

	Temperature, °F			Dew Point, °F	Cloud Cover, Fraction	Wind, MPH
	Max.	Mean	Min.			
January	57/54	48/45	38/36	38/34	.60/.63	9/11
February	60/57	50/47	41/37	40/34	.58/.62	9/12
March	67/63	57/52	47/41	44/39	.54/.61	10/12
April	75/72	65/61	55/50	54/48	.50/.55	9/11
May	83/81	73/70	63/57	62/57	.48/.55	9/9
June	91/87	81/77	71/66	69/65	.44/.58	8/8
July	92/88	82/79	72/69	71/68	.46/.63	7/8
August	94/88	83/78	73/68	70/67	.40/.57	7/8
September	88/83	78/73	67/63	65/62	.40/.53	7/8
October	79/74	67/63	55/52	55/51	.38/.45	7/9
November	66/62	55/51	45/40	45/40	.46/.51	8/10
December	59/53	50/44	40/35	39/34	.58/.62	9/10

Shreveport Lat:32.5°N, Long:94°W

Atlanta Lat:33.8°N, Long:84.4°W,

year. The net effect should be to shift the thermal plots to a slightly higher temperature but to influence the shape of the plots and the timing of stratification little. As a result, the plots for Atlanta may be used, bearing in mind that the temperatures are likely to be biased uniformly low. Figure V-5 (reproduced from Appendix D) shows thermal plots for a 20-foot deep Atlanta area impoundment having no significant inflow and low wind stress. From the figure, it is clear that the lake is likely to stratify from April or May through September, the epilimnion will be very shallow, and the thermocline will extend down to a depth of about 7 feet. The thermal gradient is in the range of about 7°C per meter, as an upper limit, during June. Bottom water warms slowly during the summer until the impoundment becomes fully mixed in October.

END OF EXAMPLE V-2

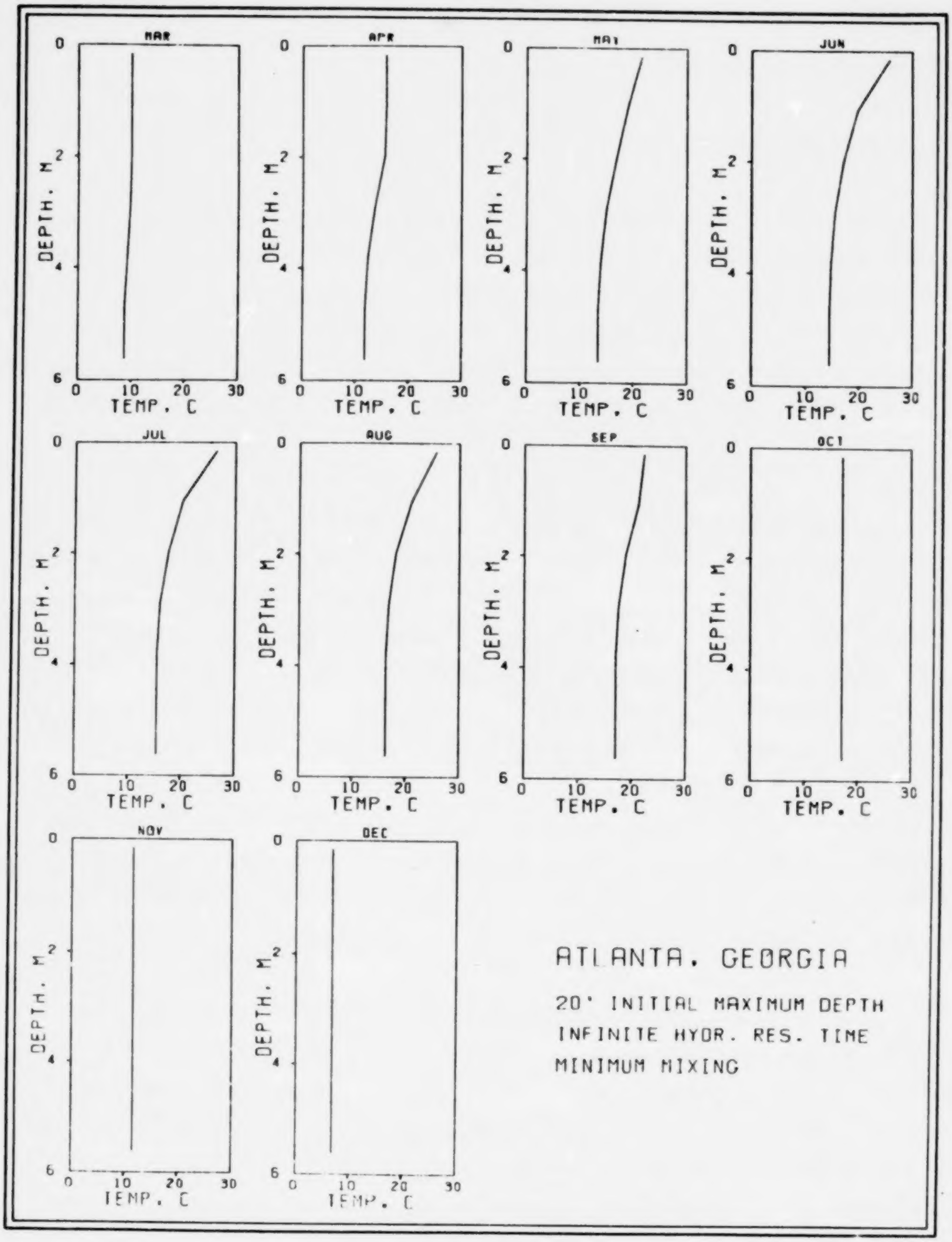


Figure V-5 Thermal Profile Plots Appropriate for Use in Example V-2

5.3 SEDIMENT ACCUMULATION

5.3.1 Introduction

Reservoirs, lakes, and other impoundments are usually more quiescent than tributary streams, and thus act as large settling basins for suspended particulate matter. Sediment deposition in impoundments gradually diminishes water storage capacity to the point where lakes fill in and reservoirs become useless. In some cases, sediment accumulation may reduce the useful life of a reservoir to as little as ten to twenty years (Marsh, *et al*., 1975).

Just how much suspended matter settles out as water passes through an impoundment, as well as the grain size distribution of matter which remains suspended, is of interest to the planner for several reasons. Suspended sediment within an impoundment may significantly reduce light penetration thus limiting algal and bottom-rooted plant (macrophyte) growth. This, in turn, can adversely affect food availability for indigenous fauna, or may slow plant succession, as part of the natural aging process of lakes.

Settling of suspended matter may eliminate harborage on impoundment bottoms thus reducing populations of desirable animal species. More directly, suspended particulates impinging on the gills of fish may cause disease or death.

Some minerals, particularly clays, are excellent adsorbents. As a result, farm chemicals and pesticides applied to the land find their way to an impoundment bottom and into its food chain. The sediment which settles is likely to have a substantial component of organic matter which can exert an oxygen demand, and under conditions of thermal stratification, anoxic conditions on the impoundment bottom (in the hypolimnion) can result in generation of toxic gases. Indigenous biota may be harmed or even killed as a result.

Knowing the rate of sediment transport and the deposition within an impoundment allows for effective planning to be initiated. If sedimentation rates are unacceptable, then the planner can begin to determine where sediments originate, and how to alleviate the problem. For example, densely planted belts may be established between highly erodible fields and transporting waterways, farming and crop management practices may be changed, or zoning may be modified to prevent a worsening of conditions.

These considerations, along with others relating to sediment carriage and deposition in downstream waterways, make estimates of sedimentation rates of interest here. Impoundment sediment computation methods discussed in this section will permit the planner to estimate annual impoundment sediment accumulation as well as short term accumulation (assuming constant hydraulic conditions). Application of the methods will permit the planner to estimate the amount of sediment removed from transport in a river system due to water passage through any number of impoundments.

5.3.2 Annual Sediment Accumulation

Three different techniques are used to estimate annual sediment accumulation, available data, sediment rating curves, and a three step procedure to determine short-term sedimentation rates. As discussed under each technique, caution should be used in selecting one method or another. If data are not available, it may not be feasible to use one or more techniques. The uncertainty in the results should be considered in drawing conclusions based on whichever analysis that is selected.

5.3.2.1 Use of Available Data

Data provided in Appendix F permit estimation of annual sediment accumulation in acre-feet for a large number of impoundments in the U.S. The data and other materials presented provide some basic impoundment statistics useful to the planner in addition to annual sediment accumulation rates.

To use Appendix F, first determine which impoundments within the study area are of interest in terms of annual sediment accumulation. Refer to the U.S. map included in the appendix and find the index numbers of the region within which the impoundment is located. The data tabulation in the appendix, total annual sediment accumulation in acre feet is given by multiplying acerage annual sediment accumulation in acre feet per square mile of net drainage area ("Annual Sediment Accum.") by the net drainage area ("Area") in square miles:

$$\text{Total Accumulation} = \text{Annual Sediment Accum.} \times \text{Area} \qquad \text{(V-2)}$$

To convert to average annual loss of capacity expressed as a percent, divide total annual accumulation by storage capacity (from Appendix F), and multiply by 100. Note that this approach, as well as those presented later, do not account for packing of the sediment under its own weight. This results in an overestimate in loss of capacity. Note also that other data in Appendix F may be of interest in terms of drainage area estimates for determining river sediment loading and assessment of storm water sediment transport on an annual basis.

5.3.2.2 Trap Efficiency and the Ratio of Capacity to Inflow

Where data are not available in Appendix F for a specific impoundment, the following method will permit estimation of annual or short-term sediment accumulation rates. The method is only useful, however, for normal ponded reservoirs.

To use this approach, a suspended sediment rating curve should be obtained for tributaries to the impoundment. An example of a sediment rating curve is provided in Figure V-6.

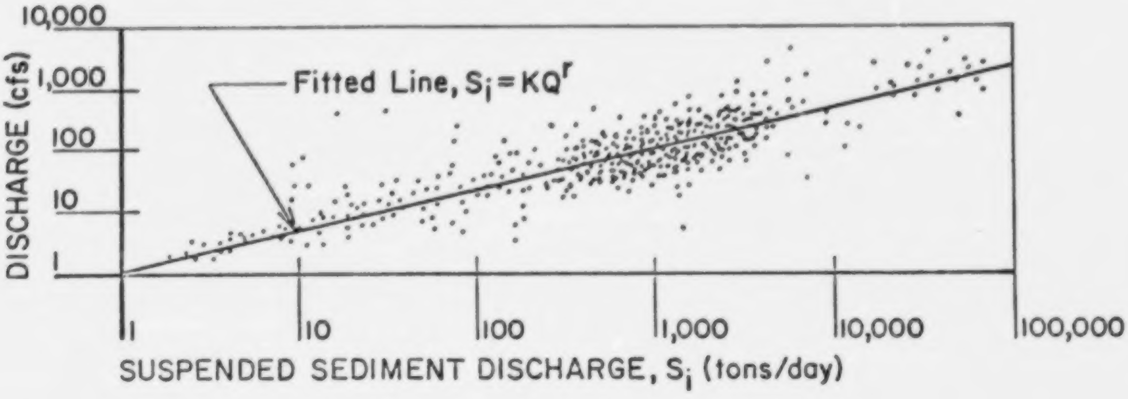


FIGURE V-6 SEDIMENT RATING CURVE SHOWING SUSPENDED SEDIMENT DISCHARGE AS A FUNCTION OF FLOW (AFTER LINSLEY, KOHLER, AND PAULHUS, 1958)

On the basis of such a curve, one can estimate the mean sediment mass transport rate (S_i) in mass per unit time for tributaries. If neither rating curve nor data are available, one may estimate sediment transport rates on a basis of data from nearby channels, compensating for differences by using mean velocities. To a first approximation, it would be expected that:

$$S_i = S_j\left(\frac{V_i}{V_j}\right)^2 \qquad \text{(V-3)}$$

where

S_i = sediment transport rate to be determined in tributary "i" in mass per unit time,

S_j = known transport rate for comparable tributary (j) in same units as S_i,

V_i = mean velocity for tributary i over the time period, and

V_j = mean velocity in tributary j over the same time period as V_i

Once average transport rates over the time period of interest have been determined, the proportion, and accordingly the weight of sediment settling out in the impoundment may be estimated. Figure V-7 is a graph showing the relationship between percent of sediment trapped in an impoundment versus the ratio of capacity to inflow rate. The implicit relationship is:

$$P = f(V/Q_i) \qquad \text{(V-4)}$$

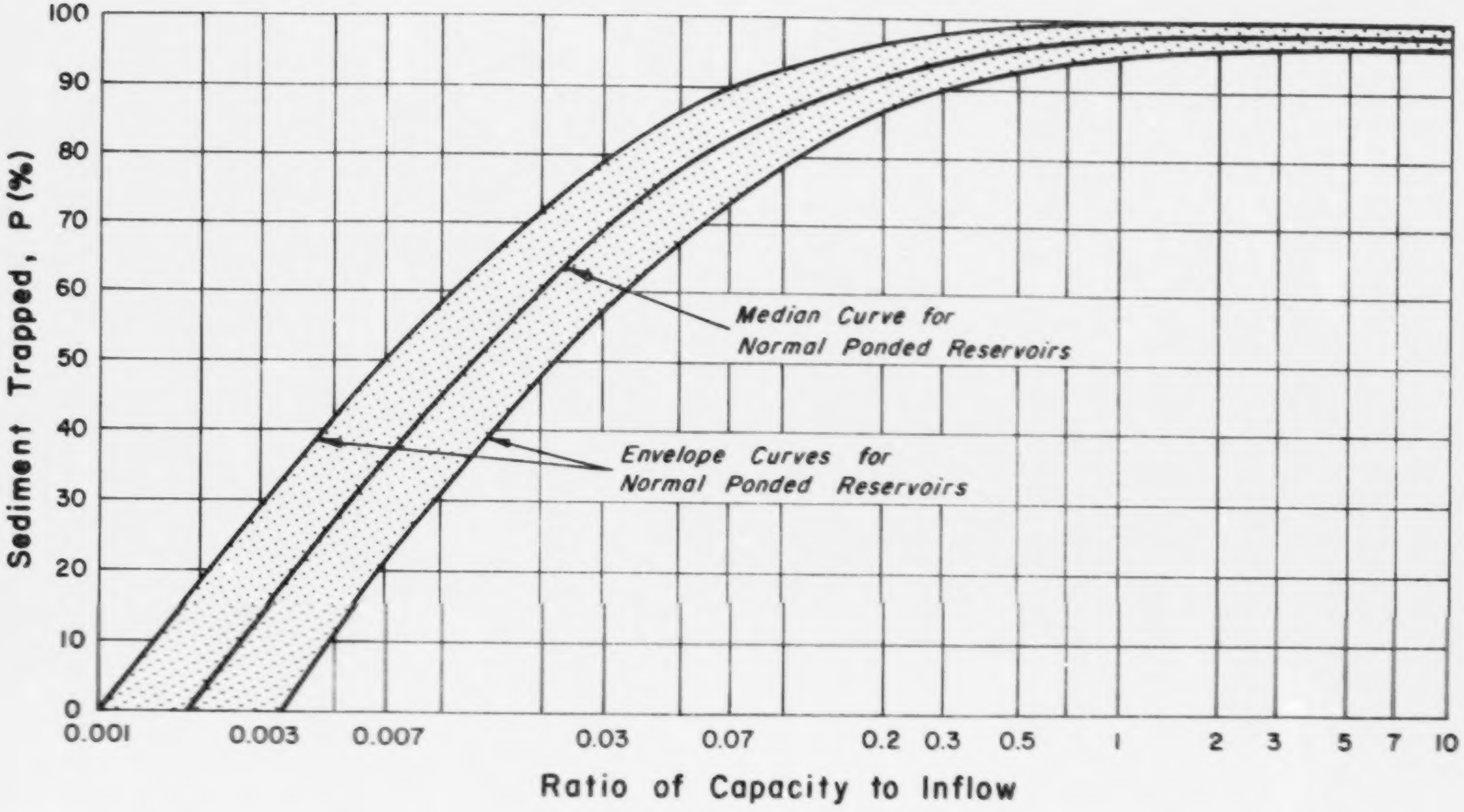


FIGURE V-7 RELATIONSHIP BETWEEN THE PERCENTAGE OF INFLOW-TRANSPORTED SEDIMENT RETAINED WITHIN AN IMPOUNDMENT AND RATIO OF CAPACITY TO INFLOW (LINSLEY, KOHLER, AND PAULHUS, 1958)

where

P = percent of inflowing sediment trapped

V = capacity of the impoundment in acre-feet, and

Q_i = water inflow rate in acre-feet per year

Data used for development of the curves in Figure V-7 included 41 impoundments of various sizes throughout the U.S. (Linsley, Kohler, and Paulhus, 1958).

To estimate the amount of suspended sediment trapped within an impoundment using this method, the capacity of the impoundment in acre-feet must first be determined. Next, average annual inflow, or better, average flow for the time period of interest is estimated.

Then,

$$S_t = S_i P \qquad \text{(V-5)}$$

where

S_t = weight of sediment trapped per time period t

P = trap efficiency (expressed as a decimal) from Figure V-7

A word of caution is in order here. The above described techniques for evaluating sediment deposition in impoundments are capable of providing reasonable estimates, but only where substantial periods of time are involved - perhaps 6 months or longer. The methods may be used for shorter study periods, but results must then be taken only as very rough estimates, perhaps order-of-magnitude.

5.3.3 Short-Term Sedimentation Rates

The three-step procedure presented below provides a means to make short-term sediment accumulation rate estimates for storm-event analysis and to estimate amounts of different grain-size fractions passing through an impoundment. The steps are:

- Determine terminal fall velocities for the grain size distribution
- Estimate hydraulic residence time
- Compute trap (sedimentation) rate

5.3.3.1 Fall Velocity Computation

When a particle is released in standing water, it will remain roughly stationary if its density equals that of the water. If the two densities differ, however, the particle will begin to rise or fall relative to the water. It will then tend to accelerate until the drag force imposed by the water exactly counterbalances the force accelerating the particle. Beyond this point, velocity is essentially constant, and the particle has reached terminal velocity. For spheres of specific gravity greater than 1, Stokes' law expresses the relationship between fall velocity (terminal velocity) and several other physical parameters of water and the particle.

$$V_{max} = \frac{g}{18\mu}(\rho_p - \rho_w)d^2 = \frac{1}{18\mu}(D_p - D_w)d^2 \qquad \text{(V-6)}$$

where

V_{max} = terminal velocity of the spherical particle (ft sec^{-1})

g = acceleration due to gravity (32.2 ft sec^{-2})

ρ_p = mass density of the particle (slugs ft^{-3})

ρ_w = mass density of water (slugs ft^{-3})

d = particle diameter (ft)

μ = absolute viscosity of the water (lb sec$\cdot$ft^{-2})

D_p = weight density of particle (lb ft^{-3})

D_w = weight density of water (lb ft^{-3})

Stokes' law is satisfactory for Reynolds numbers between 1×10^{-4} and 0.5 (Camp, 1968). Reynolds number is given by:

$$R = \frac{vd}{\nu} \qquad \text{(V-7)}$$

where

R = Reynolds number

v = particle velocity

ν = kinematic viscosity of water

Generally, for particles of diameter less than 3×10^{-2} inches (0.7 mm) this criterion is met. For large particles, how far conditions deviate from this may be observed using the following approach (Camp, 1968). According to Newton's law for drag, drag force on a particle is given by:

$$F_d = CA\rho_w v^2/2 \qquad \text{(V-8)}$$

where

F_d = the drag force

C = unitless drag coefficient

A = projected area of the particle in the direction of motion

Equating the drag force to the gravitational (driving) force for the special case of a spherical particle, velocity is given by:

$$V_{max} = \sqrt{\frac{4g\,(\rho_p - \rho_w)d}{3C \quad \rho_w}} \qquad \text{(V-9)}$$

All variables in the expression for V_{max} (Equation V-9) may be easily estimated except C, since C is dependent upon Reynold's number. According to Equation (V-7), Reynolds number is a function of v. Thus a "trial and error" or iterative procedure would ordinarily be necessary to estimate C. However, a somewhat simpler approach is available to evaluate the drag coefficient and Reynolds number. First, estimate CR^2 using the expression (Camp, 1968):

$$CR^2 = 4\rho_w\,(\rho_p - \rho_w)\,gd^3/3\mu^2 \qquad \text{(V-10)}$$

Then, using the plot in Figure V-8, estimate R and then C. For $R>0.1$ use of Equation (V-9) will give better estimates of V_{max} than will Equation (V-6).

Generally, one of the two approaches for spherical particles will give good estimates of particle fall velocity in an effectively laminar flow field (in impoundments). Occasionally, however, it may prove desirable to compensate for nonsphericity of particles. Figure V-9, which shows the effect of particle shape on the drag coefficient C, may be used to do this. Note that for $R<1$, shape of particle does not materially affect C, and no correction is necessary.

A second problem in application of the Newton/Stokes approach described above is that it does not account for what is called hindrance. Hindrance occurs when the region of fluid surrounding a falling particle is disrupted (by the particle motion) and the velocity of other nearby particles is thereby decreased. Figure V-10 shows this effect schematically.

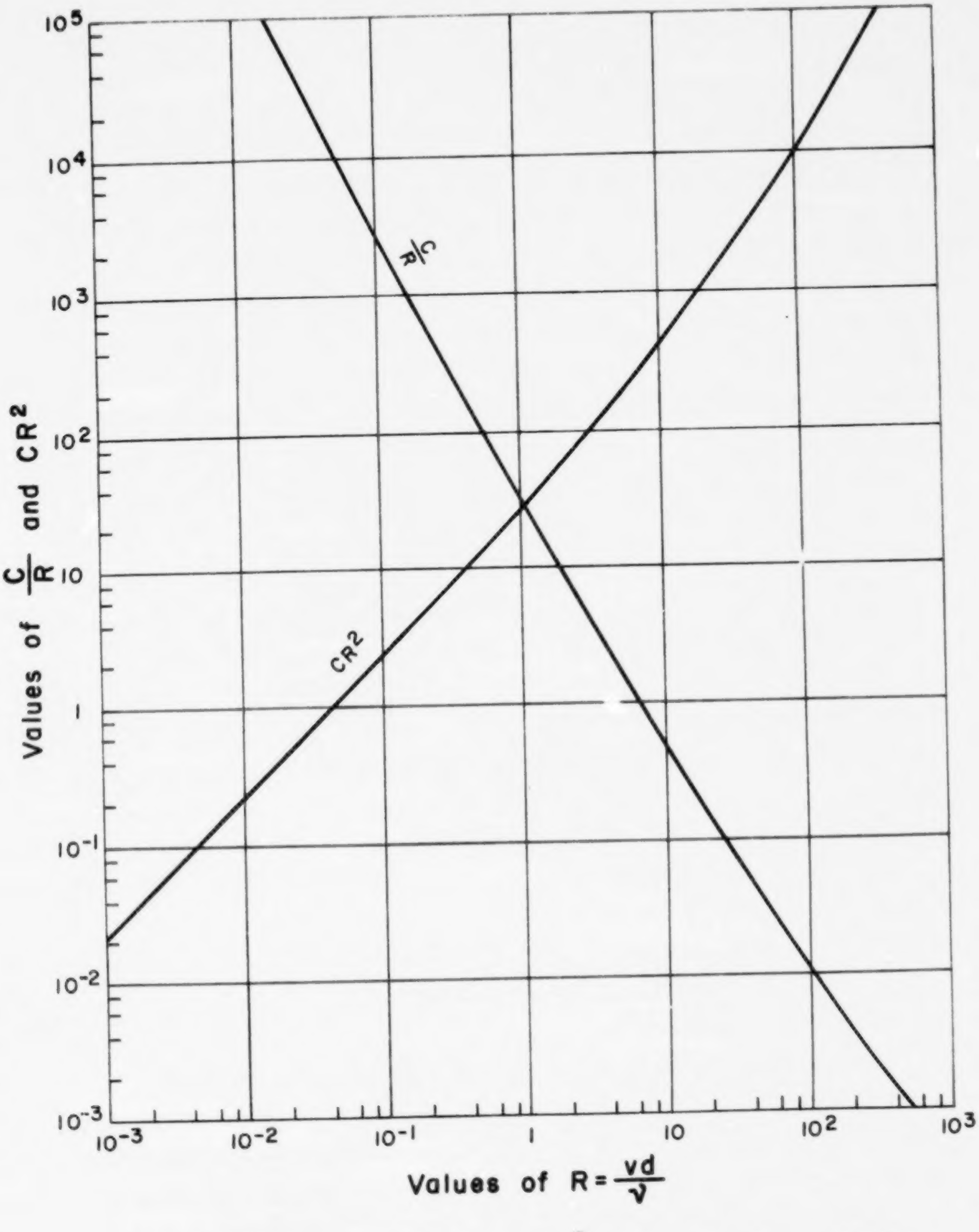


FIGURE V-8 PLOT OF C/R AND CR^2 VERSUS R (CAMP, 1968)

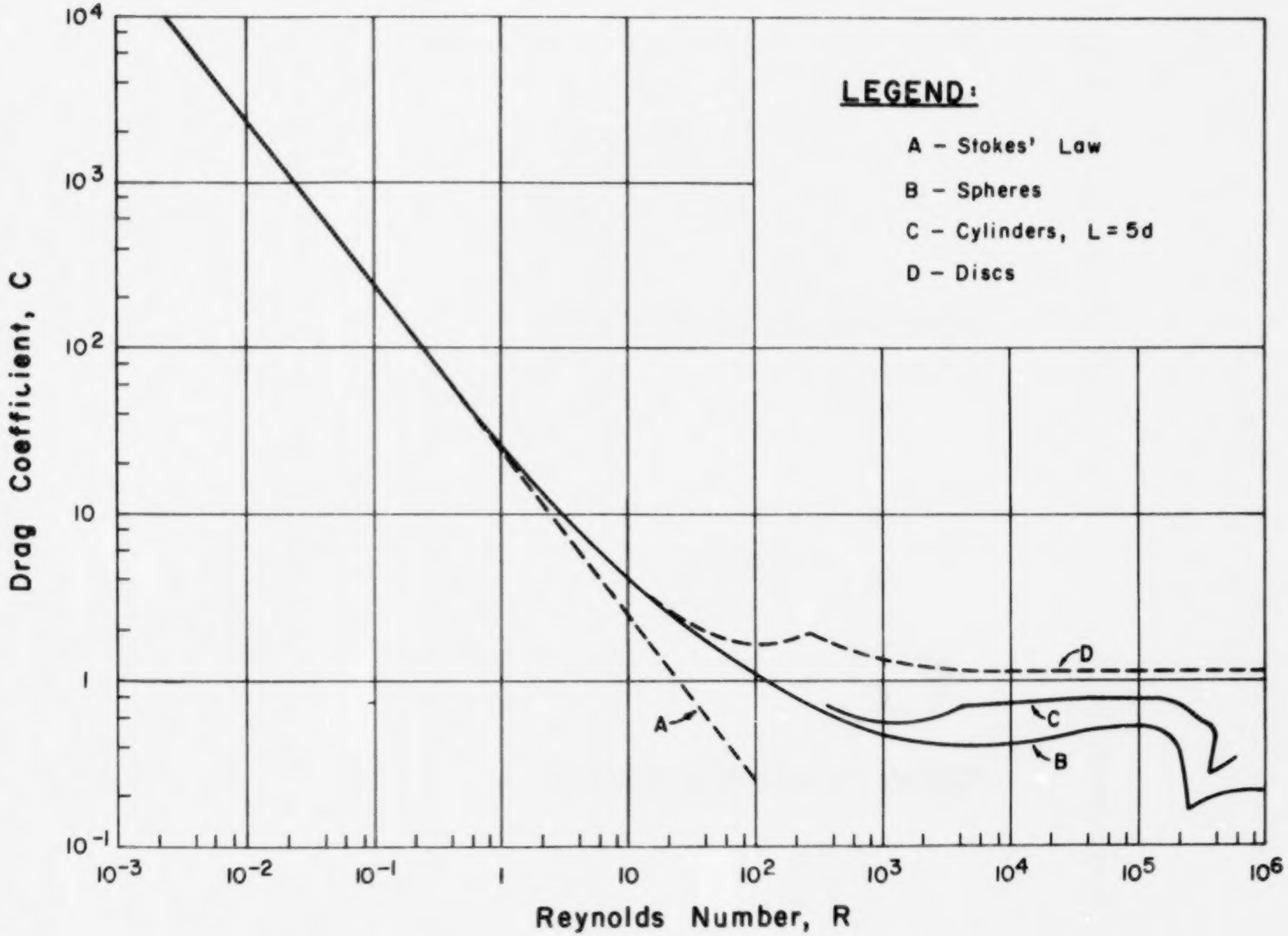


FIGURE V-9 DRAG COEFFICIENT (C) AS FUNCTION OF REYNOLD'S NUMBER (R) AND PARTICLE SHAPE (CAMP, 1968)

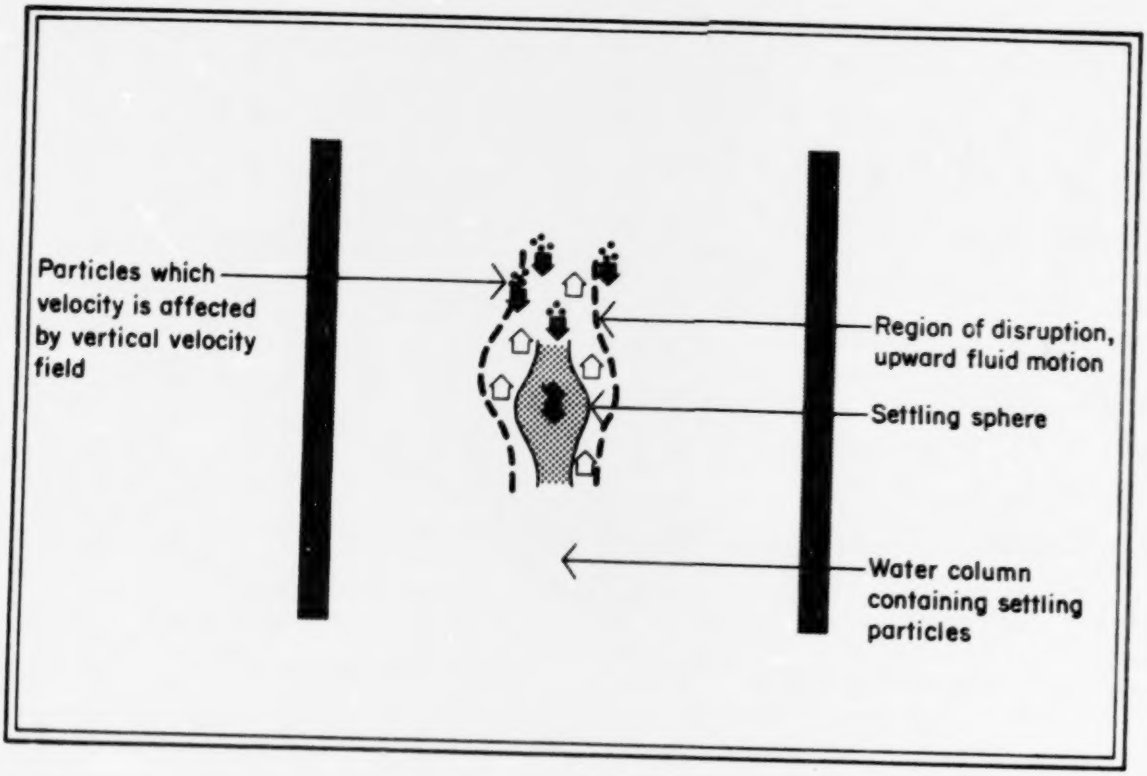

Particles which velocity is affected by vertical velocity field
Region of disruption, upward fluid motion
Settling sphere
Water column containing settling particles

FIGURE V-10 SCHEMATIC REPRESENTATION OF HINDERED SETTLING OF PARTICLES IN FLUID COLUMN

A very limited amount of research has been done to determine the effect of particle concentration on fall velocity (Camp, 1968). Some data have been collected however, and Figure V-11 is a plot of a velocity correction factor, v'/v, as a function of volumetric concentration. Volumetric concentration is given by:

$$C_{vol} = \frac{C_{wt}\rho_w}{\rho_p} \qquad \text{(V-11)}$$

where

C_{vol} = volumetric concentration

C_{wt} = weight concentration

As an approximation, the curve for sand may be used to correct v as a function of C_{vol}.

EXAMPLE V-3

Settling Velocity

Assume that a swiftly moving tributary to a large reservoir receives a heavy loading of sediment which is mostly clay particles. The particles tend to clump somewhat, and average diameters are on the order of 2 microns. The clumps have a specific gravity of 2.2. Applying Stokes' law for 20°C water,

$$V_{max} = \frac{g}{18\mu}(\rho_p - \rho_w)\, d^2$$

$$V_{max} = \frac{32.2}{(18 \times 2.1 \times 10^{-5})} \times (2.2 \times 62.4/32.2 - 62.4/32.2) \times (6.56 \times 10^{-6})^2$$

$$= 8.53 \times 10^{-6} \text{ ft sec}^{-1} = .03 \text{ ft hr}^{-1}$$

Thus the particles of clay might be expected to fall about 9 inches per day in the reservoir. It should be noted that for such a low

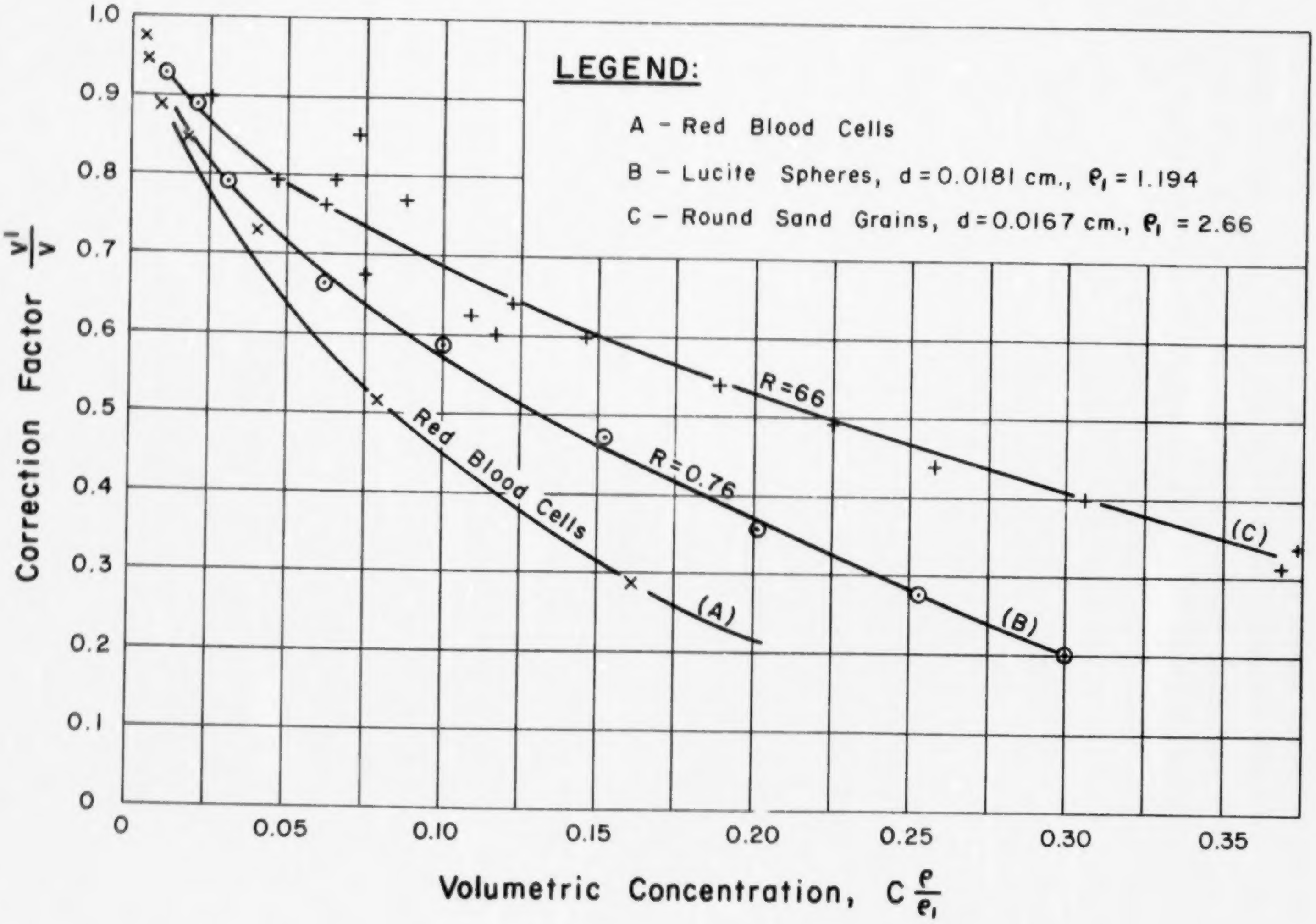


FIGURE V-11 VELOCITY CORRECTION FACTOR FOR HINDERED SETTLING (FROM CAMP, 1968)

settling rate, turbulence in the water can cause very significant errors. In fact, the estimate is useful only in still waters having a very uniform flow lacking substantial vertical components.

END OF EXAMPLE V-3

EXAMPLE V-4

Settling Velocity for a Sand and Clay

Suppose a river is transporting a substantial sediment load which is mainly sand and clay. The clay tends to clump to form particles of 10 micron diameter while the sand is of 0.2 mm diameter. The sand particles are very irregular in shape tending toward a somewhat flattened plate form. The specific gravity of the clay is about 1.8 while that of the sand is near 2.8. Given that the water temperature is about 5^{o}C, the terminal velocity of the clay may be estimated as in Example V-3:

$$V_{max} = \frac{g}{18\mu} (\rho_p - \rho_w) d^2$$

$$\begin{aligned} V_{max} &= \frac{32.2}{18 x 3.17 x 10^{-5}} \; x \; (0.8x62.4/32.2)x(3.28x10^{-5})^2 \\ &= 9.4 \; x10^{-5} \text{ ft sec}^{-1} \\ &\approx 8 \text{ ft day}^{-1} \end{aligned}$$

For the sand, apply Equation (V-10)

$$\begin{aligned} CR^2 &= 4\rho_w (\rho_p - \rho_w) gd^3/3\mu^2 \\ &= 4 \; x \; \frac{62.4}{32.2} \; x \; \frac{1.8x62.4}{32.2} \; x \; \frac{32.2 \; x \; (6.56x10^{-4})^3}{3x(3.17x10^{-5})^2} \end{aligned}$$

$$CR^2 = 82$$

Referring to Figure V-8, a value of CR^2 equal to 82 represents R≈2.8 and C≈10.3. From Figure V-9, the corrected drag coefficient for discs is close to 10.3 (no correction really necessary). Then, using Equation (V-9) as an approximation,

$$V_{max} = \sqrt{\frac{49\ (\rho_p - \rho_w)\ d}{3C\rho_w}}$$

$$V_{max} = \sqrt{\frac{4x32.2x(1.8x62.4/32.2)x6.56x10^{-4}}{3x10.3x62.4/32.2}}$$

$$V_{max} = 0.07 \text{ ft sec}^{-1} = 252 \text{ ft hr}^{-1}$$

Thus the clay will settle about 8 feet per day while the sand will settle about 6048 feet per day (252 feet per hour).

END OF EXAMPLE V-4

5.3.4 Impoundment Hydraulic Residence Time

Once settling velocities have been estimated for selected grain sizes, the final preparatory step in estimating sediment deposition rates is to compute hydraulic residence time.

Hydraulic residence time represents the mean time a particle of water resides within an impoundment. It is not, as is sometimes thought, the time required to displace all water in the impoundment with new. In some impoundments, inflowing water may be conceptualized as moving in a vertical plane from inflow to discharge. This is called plug flow. In long, narrow, shallow impoundments with high inflow velocities, this is often a good assumption. As discussed later, however, adoption of this model leads to another problem, namely, is water within the plug uniform or does sediment concentration vary over depth within the plug?

A second model assumes that water flowing into an impoundment instantaneously mixes laterally with the entire receiving layer. The layer may or may not represent the entire impoundment depth. This simplification is often a good one in large surfaced, exposed impoundments having many small inflows.

Regardless of the model assumed for the process by which water traverses an impoundment from inflow to discharge, hydraulic residence time is computed as in Equation (V-1). That is,

$$\tau_w = V/Q$$

The only important qualification is that to be meaningful, V must be computed taking account of stagnant areas, whether these are regions of the impoundment isolated from the main flow by a sand spit or promontory, or whether they are isolated by a density gradient, as in the thermocline and hypolimnion. Ignoring stagnant areas may result in a very substantial overestimate of τ_w, and in sediment trap computations, an overestimate in trap efficiency. Actually τ_w computed in this way is an adjusted hydraulic residence time. All references to hydraulic residence time in the remainder of Section 5.3 refer to adjusted τ_w.

Hydraulic residence time is directly influenced by such physical variables as impoundment depth, shape, side slope, and shoaling, as well as hydraulic characteristics such as degree of mixing, stratification, and flow velocity distributions. The concepts involved in evaluating many of these factors are elementary. The evaluation itself is complicated, however, by irregularities in impoundment shape and data inadequacies. Commonly, an impoundment cannot be represented well by a simple 3-dimensional figure, and shoaling and other factors may restrict flow to a laterally narrow swath through the water body.

In most cases, hydraulic residence time may be estimated, although it is clear that certain circumstances tend to make the computation error-prone. The first step in the estimation process is to obtain impoundment inflow, discharge, and thermal regime data as well as topographic/bathymetric maps of the system. Since a number of configuration types are possible, the methods are perhaps best explained using examples.

EXAMPLE V-5

Hydraulic Residence Time in Unstratified Impoundments

The first step in estimating hydraulic residence time for purposes of sedimentation analysis is to determine whether there are significant stagnant areas. These would include not only regions cut off from the main flow through the body, but also layers isolated by dense strata. Consequently, it must be determined whether or not the impoundment stratifies. Consider Upper Lake located on the Carmans River, Long Island, New York. The lake and surrounding region are shown in Figure V-12, and hypothetical geometry data are presented in Table V-6. Based upon Upper Lake's shallowness, its long, narrow geometry, and high tributary inflows, it is safe to assume that Upper Lake is normally unstratified. Also, because of turbulence likely at the high flows, one can assume that the small sac northeast of the discharge is not stagnant and that Upper Lake represents a slow moving river reach. With these assumptions, the computation of hydraulic residence time is as shown in Table V-6.

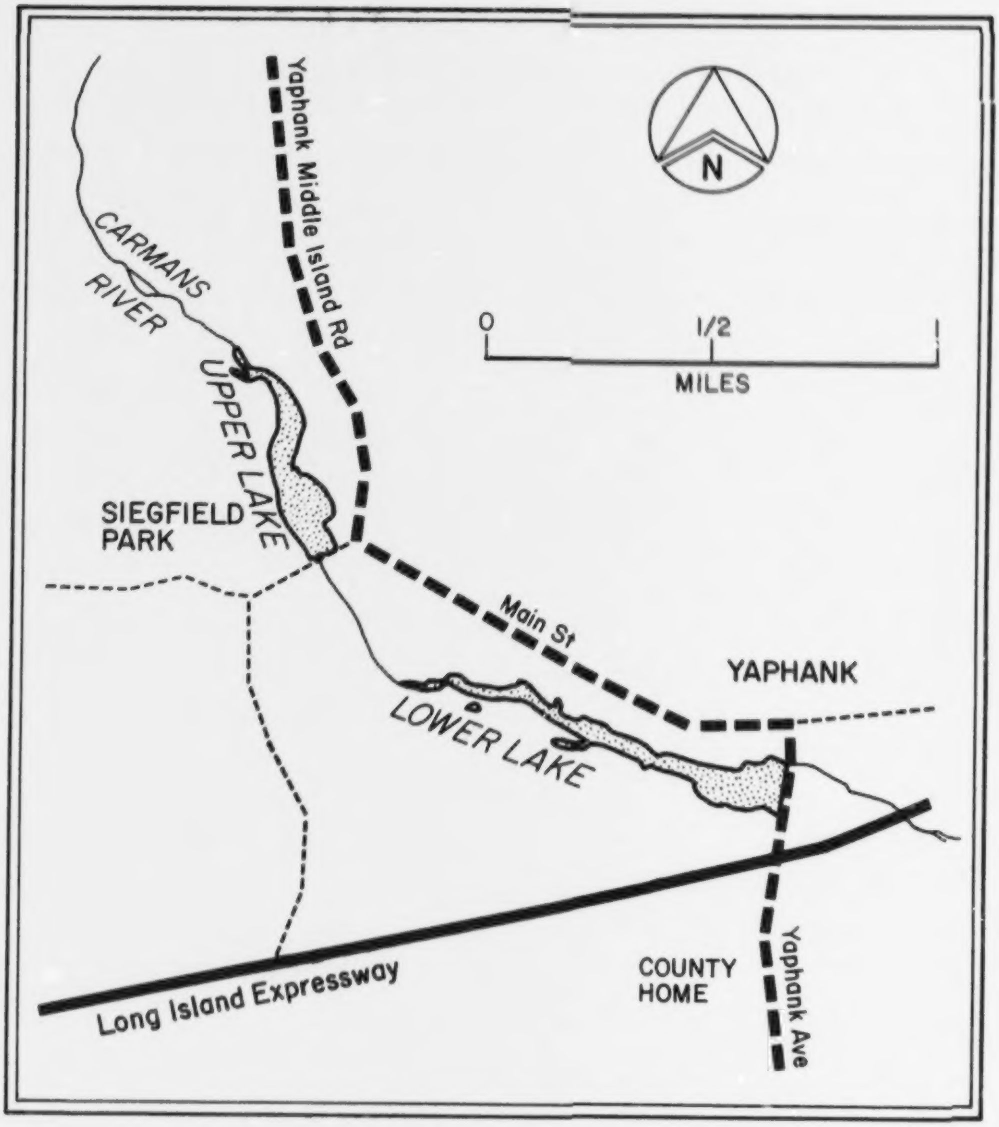


Figure V-12 Upper and Lower Lakes and Environs, Long Island, New York

TABLE V-6

HYPOTHETICAL PHYSICAL CHARACTERISTICS OF UPPER LAKE, BROOKHAVEN, SUFFOLK COUNTY, NEW YORK

Distance Downstream from Inflow Miles (feet)	D Average Depth ft.	W Average Width ft.	CSA Cross-sectional Area, D x W ft^2
0.05 (264)	3	63	189
0.10 (528)	4	110	440
0.15 (792)	6	236	1,416
0.20 (1,056)	7	315	2,205
0.25 (1,320)	7	340	2,380
0.30 (1,584)	8	315	2,520
0.35 (1,848)	7	550	3,850
0.40 (2,112)	8	550	4,400
0.45 (2,376)	7	354	2,478
0.50 (2,640)	10	350	3,500

Total length = 0.5 mi. (2,640 ft.) mean CSA = 2,338 ft^2

$$\left.\begin{array}{l}\text{Inflow from upstream = 380 cfs}\\\text{Outflow to downstream = 380 cfs}\end{array}\right\}\text{(steady-state)}$$

Computation

Volume (Vol) = Total length x mean cross-sectional area

$$\text{Vol} = 2{,}640\text{ ft.} \times 2{,}338\text{ ft}^2 = 6.17 \times 10^6\text{ ft}^3$$

Residence time (τ_w) = Vol/flow

$$\tau_w = 6.17 \times 10^6\text{ ft}^3/(380\text{ ft}^3/\text{sec}) = 1.62 \times 10^4\text{ sec (4.5 hr)}$$

Velocity (Vel) = length/τ_w

$$\text{Vel} = 2{,}640\text{ ft}/1.62 \times 10^4\text{ sec} = .163\text{ ft/sec}$$

Also shown in Figure V-12 is Lower Lake. According to the hypothetical data presented in Table V-7, Lower Lake is much deeper than Upper Lake. Its volume is significantly greater also, but the inflow rate is similar. In this case, particularly during the summer, it should be determined if the lake stratifies. For this example, however, we will assume that the time of the year makes stratification very unlikely, and that Lower Lake is a slow moving river reach. We then compute hydraulic residence time as shown in Table V-7. Figure V-13 in particular diagram 1, shows what these assumptions mean in terms of a flow pattern for both lakes.

——————— END OF EXAMPLE V-5 ———————

——————— EXAMPLE V-6 ———————

Assume for this example that Lower Lake is stratified during the period of interest. This significantly changes the computation of residence time. To a first approximation, one can merely revise the effective depth of the impoundment to be from the surface to the upper limit of the thermocline rather than to the bottom. Figure V-13 shows schematically what this simple model suggests for Lower Lake as a stratified impoundment (diagram 2 or possibly 3). The figure also shows wind-driven shallow, and deep impoundments. To the right of each diagram is a plot of the temperature profile over depth. Actually, the profile could represent a salinity gradient as well as a thermal gradient.

Table V-8 shows the procedure to estimate travel time for stratified Lower Lake. The upper boundary of the thermocline is assumed to be at a depth of 10 feet. For all later computations of sediment accumulation, this same 10 foot depth would be adopted. Such an assumption is valid presuming that the thermocline and hypolimnion are relatively quiescent. Thus once a particle enters the thermocline it can only settle, and can not leave the impoundment.

——————— END OF EXAMPLE V-6 ———————

TABLE V-7

HYPOTHETICAL PHYSICAL CHARACTERISTICS OF LOWER LAKE, BROOKHAVEN, SUFFOLK COUNTY, NEW YORK

Distance Downstream from Inflow Miles (feet)	D Average Depth ft.	W Average Width ft.	CSA Cross-sectional Area, D x W ft^2
0.075 (396)	15	157	2,355
0.150 (792)	20	165	3,300
0.225 (1,188)	20	173	3,460
0.300 (1,584)	25	197	4,925
0.375 (1,980)	35	197	6,895
0.450 (2,376)	30	228	6,840
0.525 (2,772)	35	232	8,120
0.600 (3,168)	35	197	6,895
0.675 (3,564)	40	220	8,800
0.750 (3,960)	42	315	13,230
0.825 (4,356)	41	433	17,753
0.900 (4,752)	51	591	30,141
0.975 (5,148)	42	551	23,142
1.050 (5,544)	40	433	17,320
1.125 (5,940)	37	323	11,951

Total length = 1.125 mi (5,940 ft.) mean CSA = 11,008

Inflow from upstream 400 cfs
Outflow to downstream 390 cfs } (surface rising)

Average flow = 395 cfs

Computation

Volume (Vol) = Total length x mean cross-sectional area

$$\text{Vol} = 5{,}940 \text{ ft.} \times 11{,}008 \text{ ft}^2 = 6.54 \times 10^7 \text{ ft}^3$$

Residence Time (τ_w) = Vol/flow

$$\tau_w = 6.54 \times 10^7/(395 \text{ ft}^3/\text{sec}) = 1.65 \times 10^5 \text{ sec (46 hr)}$$

Velocity (Vel) = length/τ_w

$$\text{Vel} = 5{,}940 \text{ ft}/1.65 \times 10^5 \text{ sec} = .036 \text{ ft/sec}$$

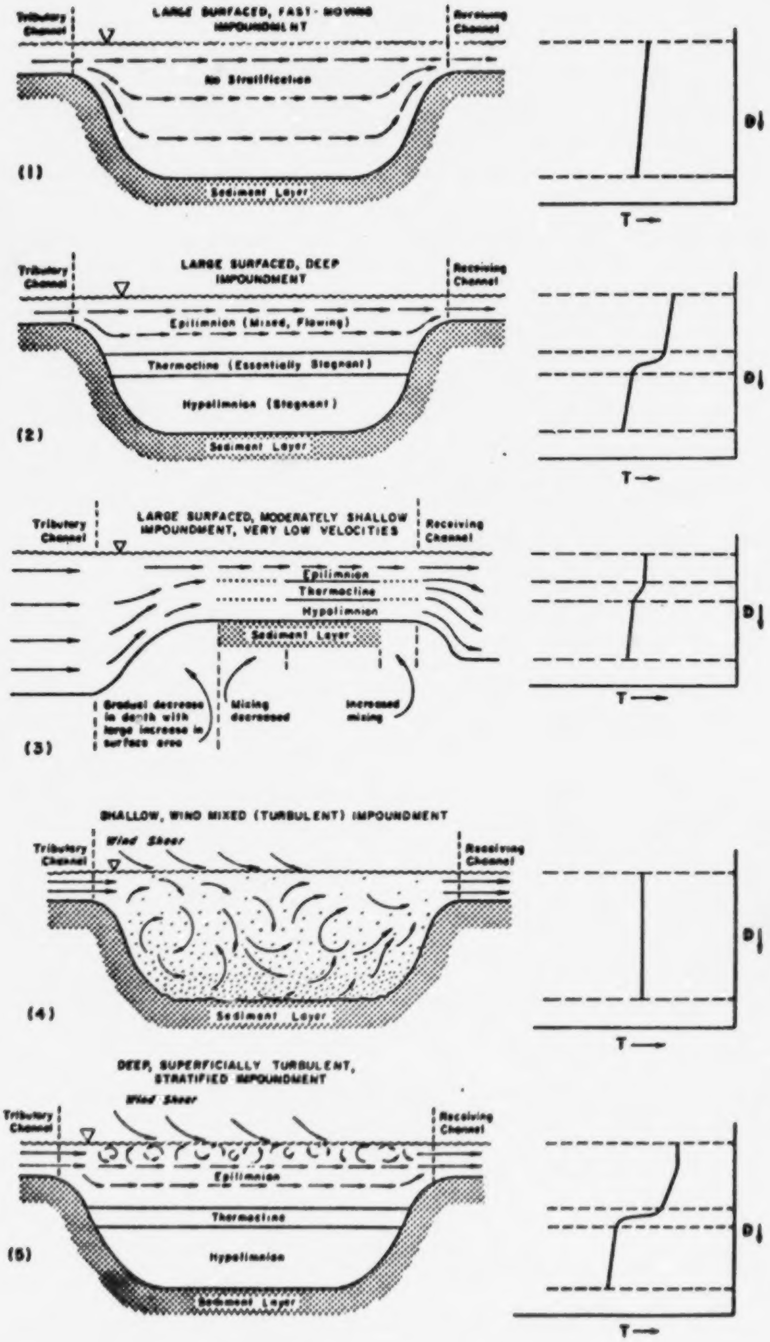


FIGURE V-13 IMPOUNDMENT CONFIGURATIONS AFFECTING SEDIMENTATION

TABLE V-8

HYPOTHETICAL PHYSICAL CHARACTERISTICS OF LOWER LAKE, BROOKHAVEN, SUFFOLK COUNTY, NEW YORK (ASSUMING AN EPILIMNION DEPTH OF 10 FEET)

Distance Downstream from Inflow Miles (feet)	D Average Depth ft.	W Average Width ft.	CSA Cross-sectional Area, D x W ft^2
0.075	10	160	1,600
0.150	10	170	1,700
0.225	10	175	1,750
0.300	10	200	2,000
0.375	10	198	1,980
0.450	10	230	2,300
0.525	10	233	2,330
0.600	10	200	2,000
0.675	10	222	2,220
0.750	10	316	3,160
0.825	10	435	4,350
0.900	10	590	5,900
0.975	10	552	5,520
1.050	10	435	4,350
1.125	10	325	3,250

Total length = 1.125 mi (5,940 ft.) mean CSA = 2,961 ft^2

Inflow from upstream 397 cfs
Outflow to downstream 393 cfs
} (steady-state surface, difference due to loss to water table)

Average flow = 395 cfs

Computation

Volume (Vol) = Total length x mean cross-sectional area

$$Vol = 5{,}940 \text{ ft.} \times 2{,}961 \text{ ft}^2 = 1.76 \times 10^7$$

Residence Time (τ_w) = Vol/flow

$$\tau_w = 1.76 \times 10^7/(395 \text{ ft}^3/\text{sec}) = 4.46 \times 10^4 \text{ sec (12.3 hr)}$$

Velocity (Vel) = length/τ_w

$$Vel = 5{,}940 \text{ ft}/4.46 \times 10^4 \text{ sec} = 0.133 \text{ ft/sec}$$

EXAMPLE V-7

Large, Irregular Surface Impoundment

Figure V-14 shows Kellis Pond and surrounding topography. This small pond is located near Bridgehampton, New York and has a surface area of about 36 acres. From the surface shape of the pond, it is clear that it cannot be considered as a stream reach.

Figure V-15 shows a set of hypothetical depth profiles for the pond. From the profiles, it is evident that considerable shoaling has resulted in the formation of a relatively well defined flow channel through the pond. Peripheral stagnant areas have also formed. Hypothetical velocity vectors for the pond are presented in Figure V-16. Based upon them, it is reasonable to consider the pond as being essentially the hatched area in Figure V-15. To estimate travel times, the hatched area may be handled in the same way as for the Upper Lake example presented above. It should be noted, however, that this approach will almost certainly result in underestimation of sediment deposition in later computations. This is true for two reasons. First, estimated travel time will be smaller than the true value since impoundment volume is underestimated. Second, since the approach ignores the low flow velocities to either side of the central channel and nonuniform velocities within it, heavier sedimentation than computed is likely.

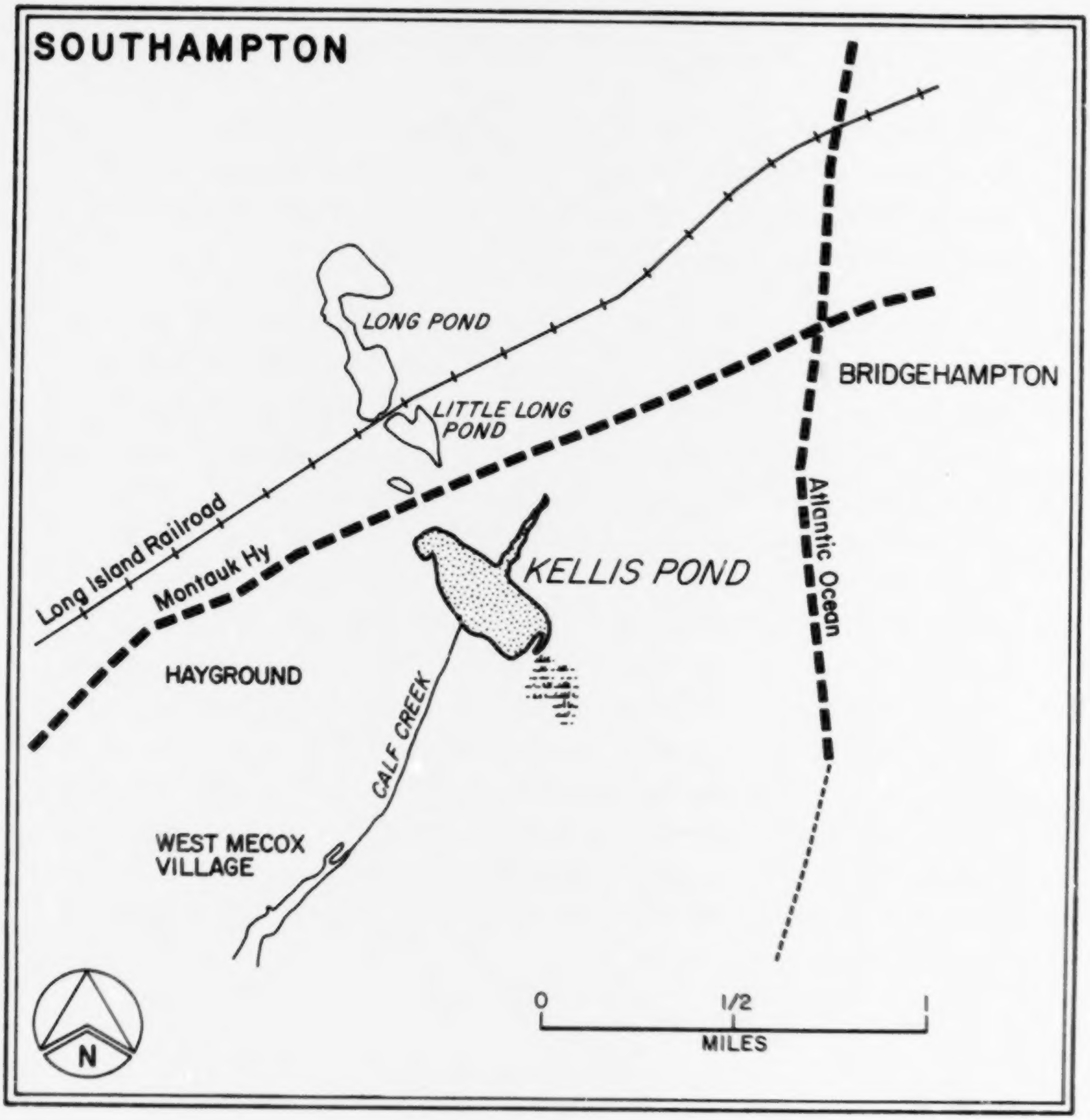


FIGURE V-14 KELLIS POND AND SURROUNDING REGION, LONG ISLAND, NEW YORK

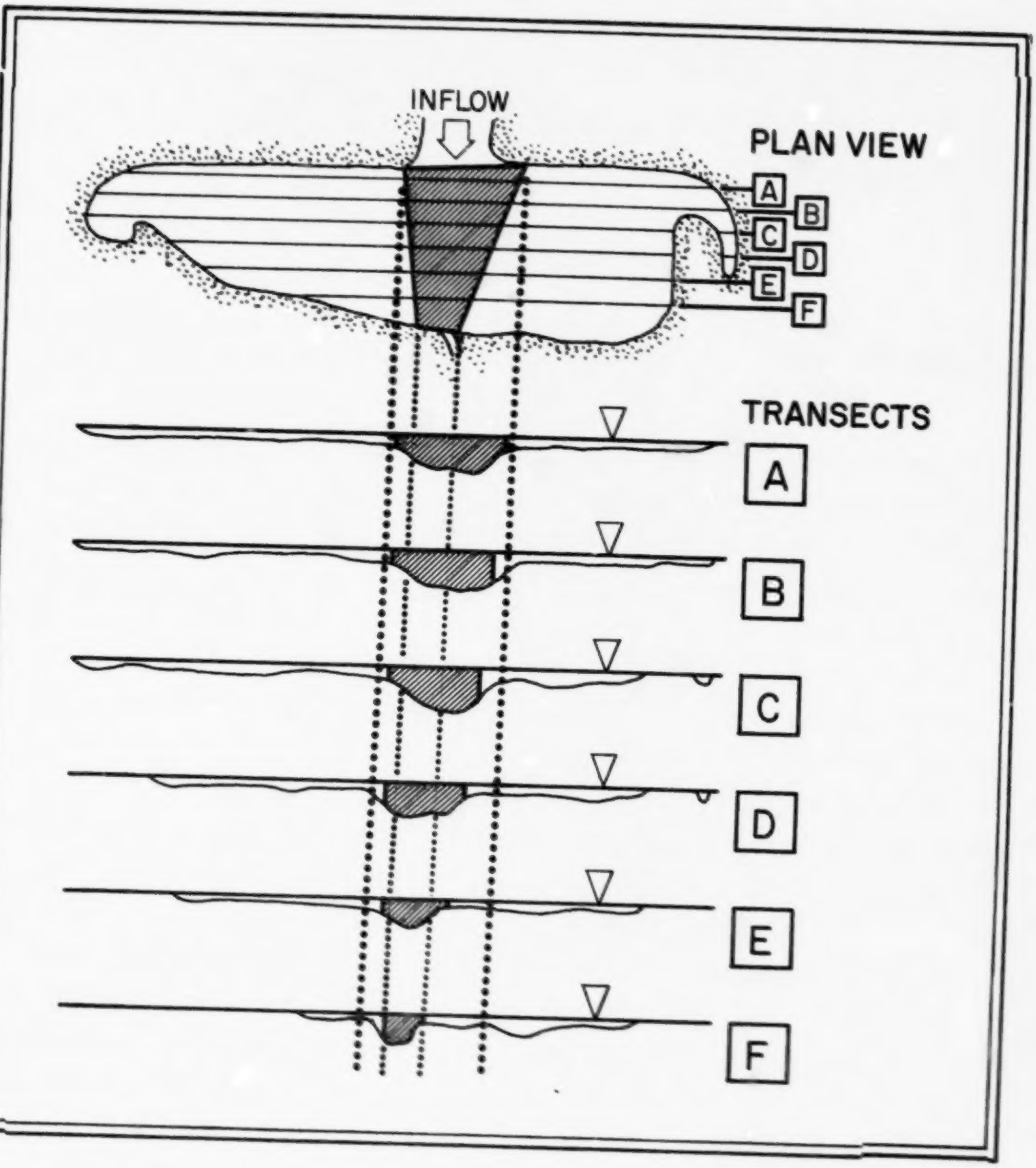


Figure V-15 Hypothetical Depth Profiles for Kellis Pond

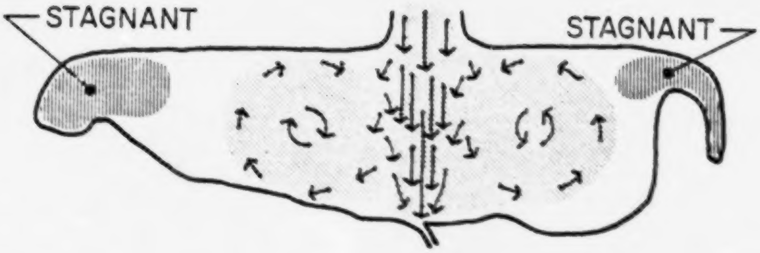


FIGURE V-16 HYPOTHETICAL FLOW PATTERN IN KELLIS POND

Still more difficult to evaluate is the situation where shoaling and scour have not resulted in formation of a distinct central channel. Figure V-17 shows hypothetical depth profiles for Kellis Pond for such a case.

Here, velocity distribution data should be obtained, particularly if the impoundment is of much importance. If such data are not available but it is deemed worthwhile to do field studies, methods available for evaluating flow patterns include dye tracing and drogue floats. A simple but adequate method (at least to evaluate the surface velocity distribution) is to pour a large number of citrus fruits (oranges, grapefruit) which float just below the surface, into the impoundment, and to monitor both their paths and velocities. Although it is true that surface velocities may be greater than the velocity averaged over depth, this will permit estimation of hydraulic residence time directly or generation of data to use in the prescribed method. In the latter case, the data might be used to define the major flow path through an impoundment of a form like Kellis Pond.

END OF EXAMPLE V-7

EXAMPLE V-8

Complex Geometries

The final hydraulic residence time example shows the degree of complexity that sediment deposition problems may entail. Although it is possible to make rough estimates of sediment accumulation, it

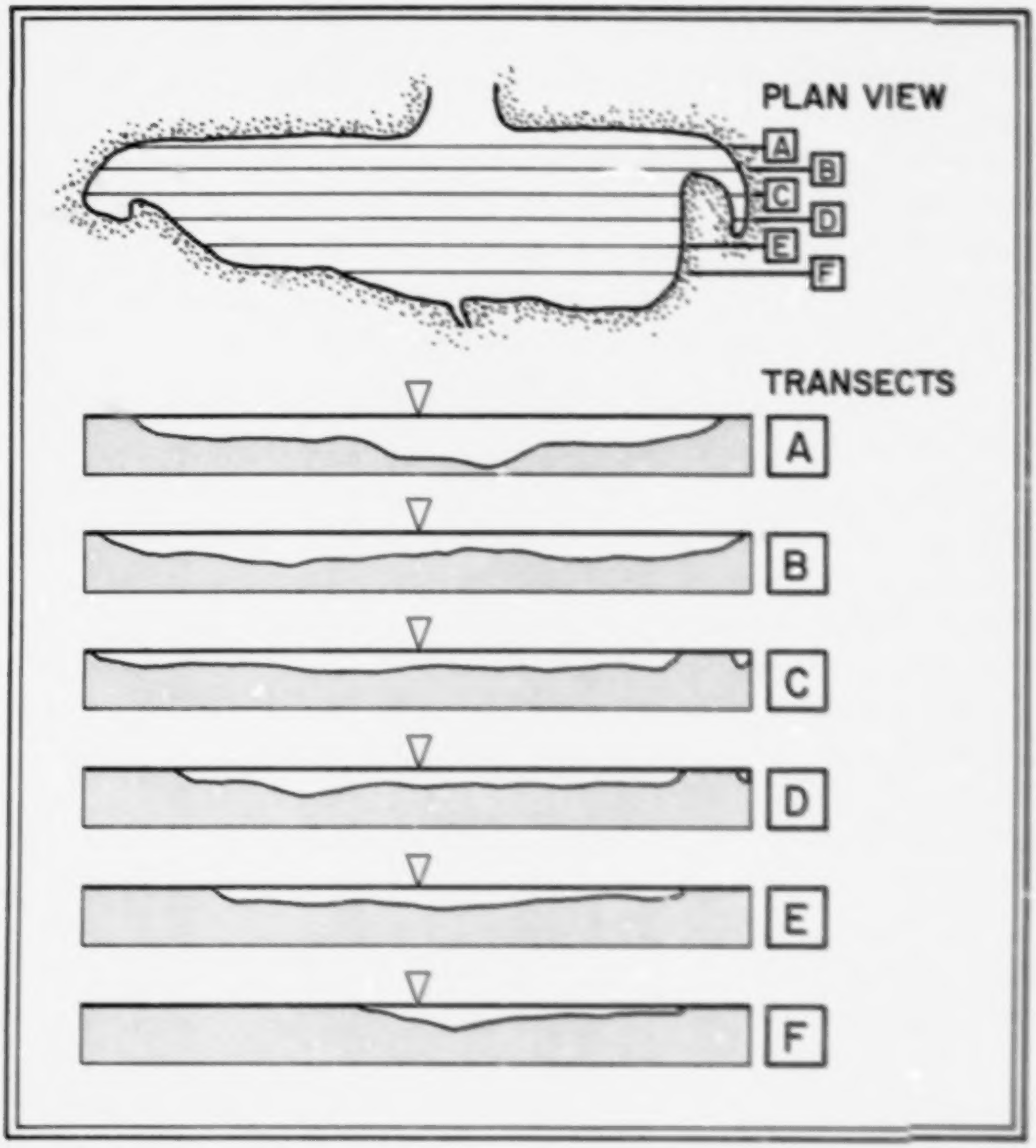


Figure V-17 Hypothetical Depth Profiles for Kellis Pond Not Showing Significant Shoaling

is recommended that for such impoundments more rigorous methods be used - mathematical modeling and/or detailed field investigations.

Figure V-18 shows Lake Owyhee in eastern Oregon. This impoundment is well outside the range of complexity of water bodies which can be evaluated using these calculation methods. Because of geometry, the number of tributaries, and size, it isn't feasible to conceptually reduce the impoundment in such a way as to estimate travel times. Flow patterns are likely to be very complex, and sediment deposition is difficult to predict both in terms of quantity and location.

In contrast, Figure V-19 shows New Millpond near Islip, New York and surrounding features. Although this water body does not have a simple surface geometry, it can be reduced to three relatively simple components as shown in the figure. Bearing in mind the limitations imposed by wind mixing, stratification, and the presence of stagnant regions described in earlier examples, deposition might nevertheless be estimated in arms A, B, and C. Because of the difficulty of predicting velocities and turbulence in section D, estimates of sedimentation cannot be reliably made there. However, it is likely that much of inflowing sediments will have settled out by the time water flows through the arms and into section D.

END OF EXAMPLE V-8

5.3.5 Estimation of Sediment Accumulation

Estimation of quantities of sediment retained in an impoundment follows directly from the computations of settling velocity and travel time, although the computation depends upon whether the adopted model is plug flow, or a fully mixed layer or impoundment.

In the case of plug flow, one of two subordinate assumptions is made: that the plug is fully mixed as in turbulent flow, or that it moves in a "laminar" flow through the impoundment. In terms of sediment accumulation estimates, the fully mixed plug assumption is

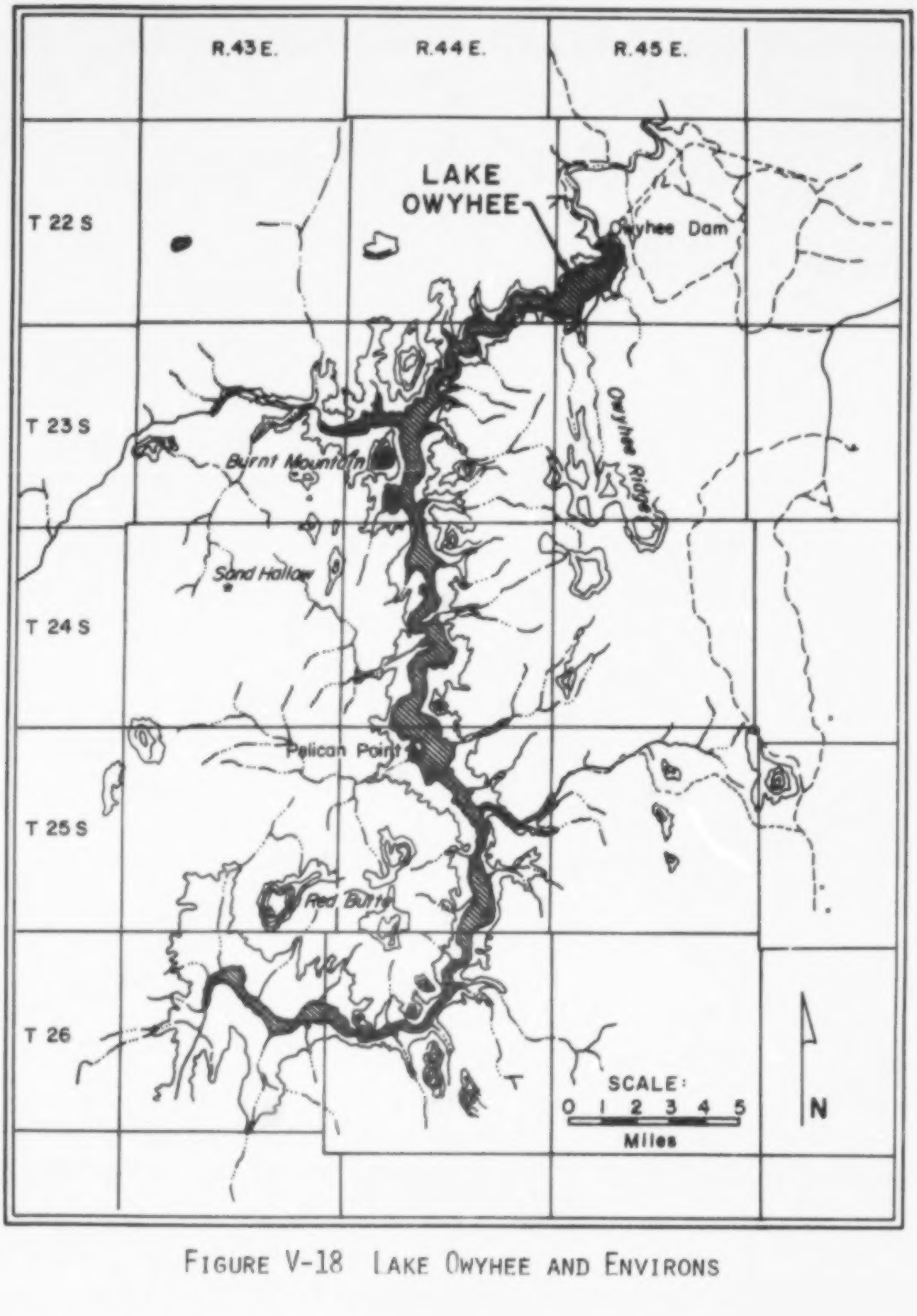


FIGURE V-18 LAKE OWYHEE AND ENVIRONS

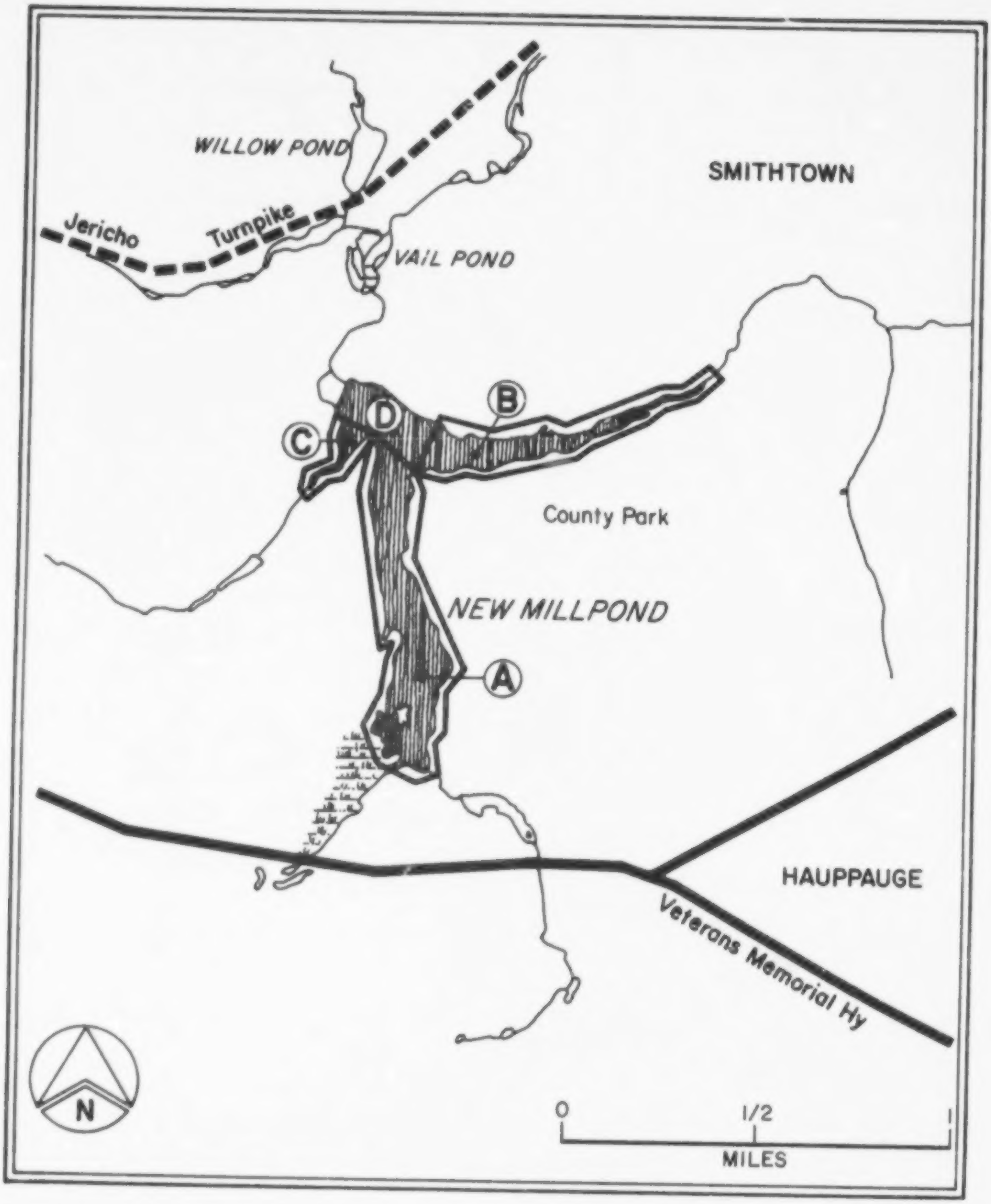


FIGURE V-19 NEW MILLPOND AND ENVIRONS. NEW MILLPOND IS SUBDIVIDED FOR PURPOSES OF ESTIMATING SEDIMENTATION IN REGIONS A, B, AND C.

handled in the same way as the fully mixed impoundment model. Thus we have two kinds of computations:

Cases

A
- Plug flow with the plug not mixed vertically

versus

B
- Plug flow assuming a vertically mixed plug, or
- A fully mixed impoundment or stratum

Equation (V-12) is pertinent to both cases A and B. It defines the mass of sediment trapped as a function of trap efficiency and inflowing sediment mass. Equation (V-13) should be used for case A, and Equation (V-14) for case B.

$$S_t = S_i P \tag{V-12}$$

$$P = \left((\tau_w v) + D'' - D \right) / D'' \tag{V-13}$$

$$P = \frac{v\tau_w}{D'} \tag{V-14}$$

where

P = mean proportion of S_i trapped ($1 \geq P \geq 0$)

S_t = mass of sediment trapped per unit time

S_i = mass of sediment in inflows per unit time

v = particle settling velocity

D = discharge channel depth

D' = flowing layer depth

D'' = inflow channel depth

Figure V-20 shows the significance of the various depth measures D, D', and D'', and the assumed sedimentation pattern. In case B, in the absence of substantial erratic turbulence and unpredicted vertical velocity components, and within the constraints of available data, it is clear that this approach can give reasonable estimates of trap efficiencies. In case A, however, small changes in D or D'' can strongly affect trap efficiencies. It is important to remember in applying case A that P is a mean, preferably used over a period of time. It is also important to recognize that conditions within an impoundment leading to selection of case A or B are subject to change, thus affecting estimates.

For convenience, Figure V-21 is included to provide estimates of v_{max} for spherical particles of 2.7 specific gravity. The data are presented as a function of particle diameter and temperature. Figure V-22 is a nomograph relating trap efficiency, P (in percent) to depth D', V_{max}, and τ_w. The nomograph is useful only for case B assumptions.

EXAMPLE V-9

Sedimentation in Upper and Lower Lakes

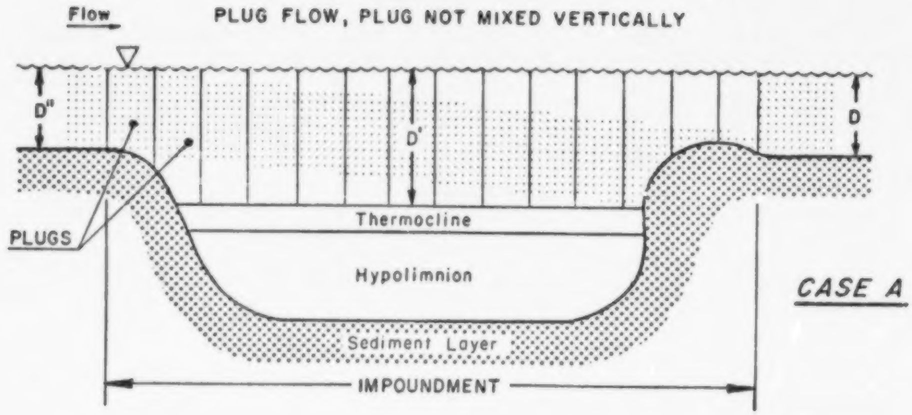
Using the data from Table V-6 and settling velocities for the clay and sand of Example V-4, for case A,

$$\tau_w = 1.6\text{x}10^4 \text{ sec}$$

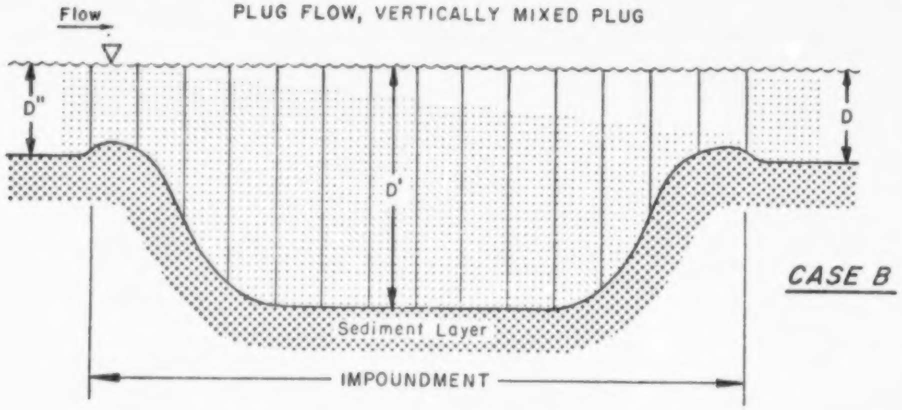
$$V_{max} \text{ for clay} = 8 \text{ ft day}^{-1}$$

$$V_{max} \text{ for sand} = 252 \text{ ft hour}^{-1}$$

PLUG FLOW, PLUG NOT MIXED VERTICALLY



PLUG FLOW, VERTICALLY MIXED PLUG



FULLY MIXED IMPOUNDMENT OR STRATUM

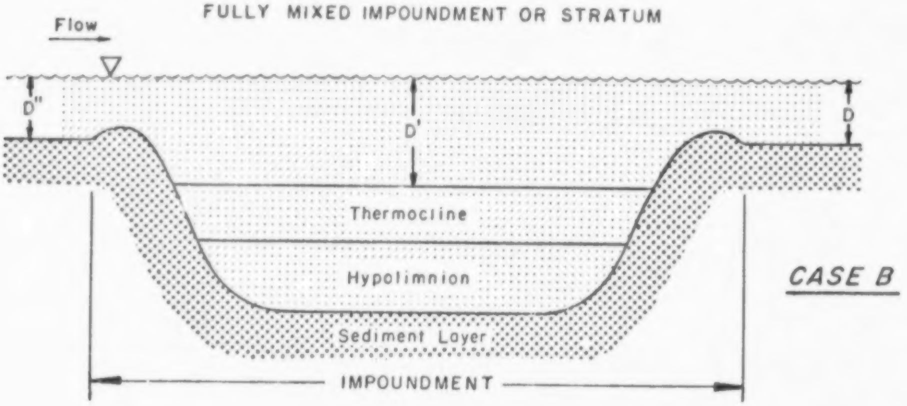


Figure 20 Significance of Depth Measures D, D^1, and D^{11}, and the Assumed Sedimentation Pattern

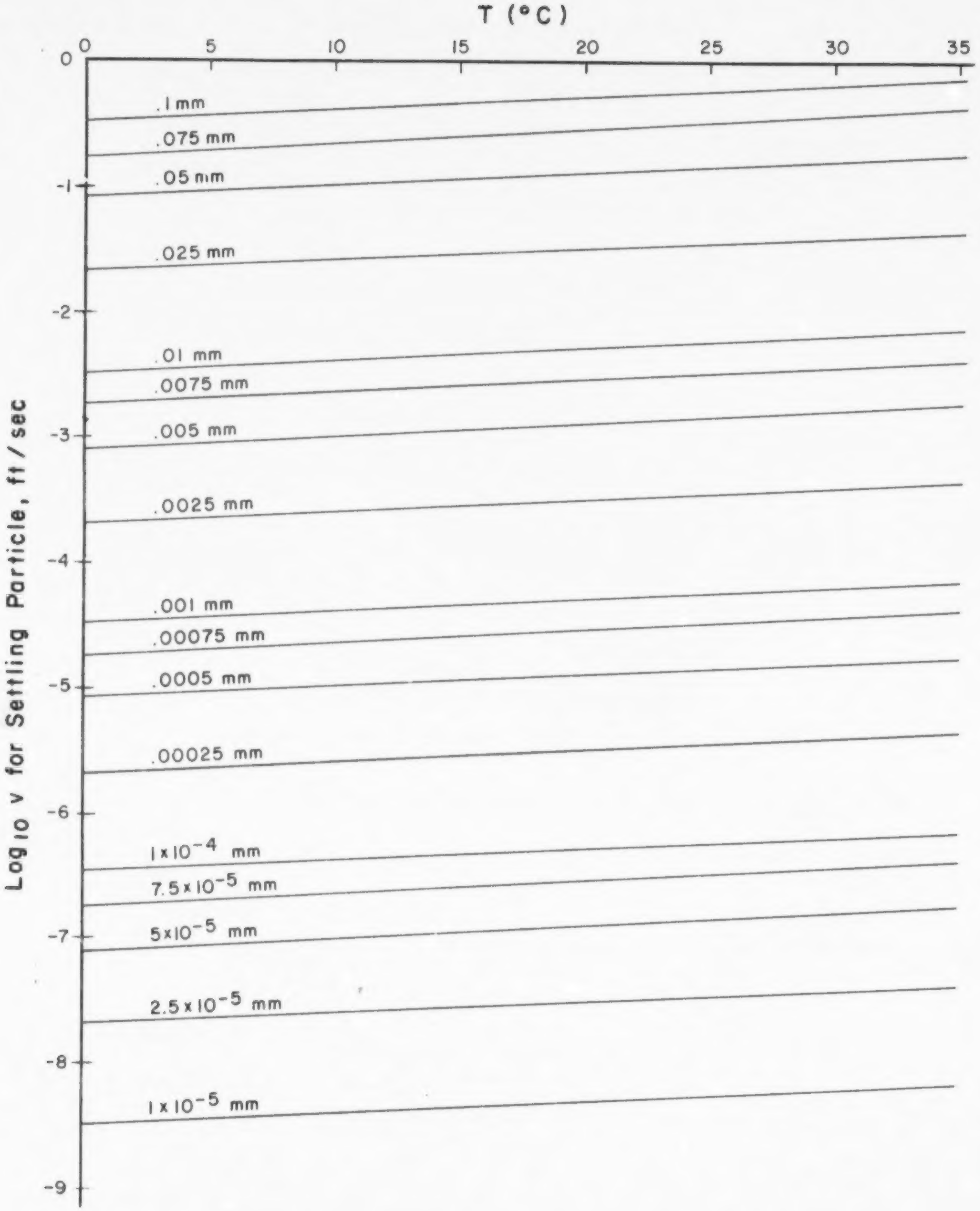


FIGURE V-21 SETTLING VELOCITY FOR SPHERICAL PARTICLES

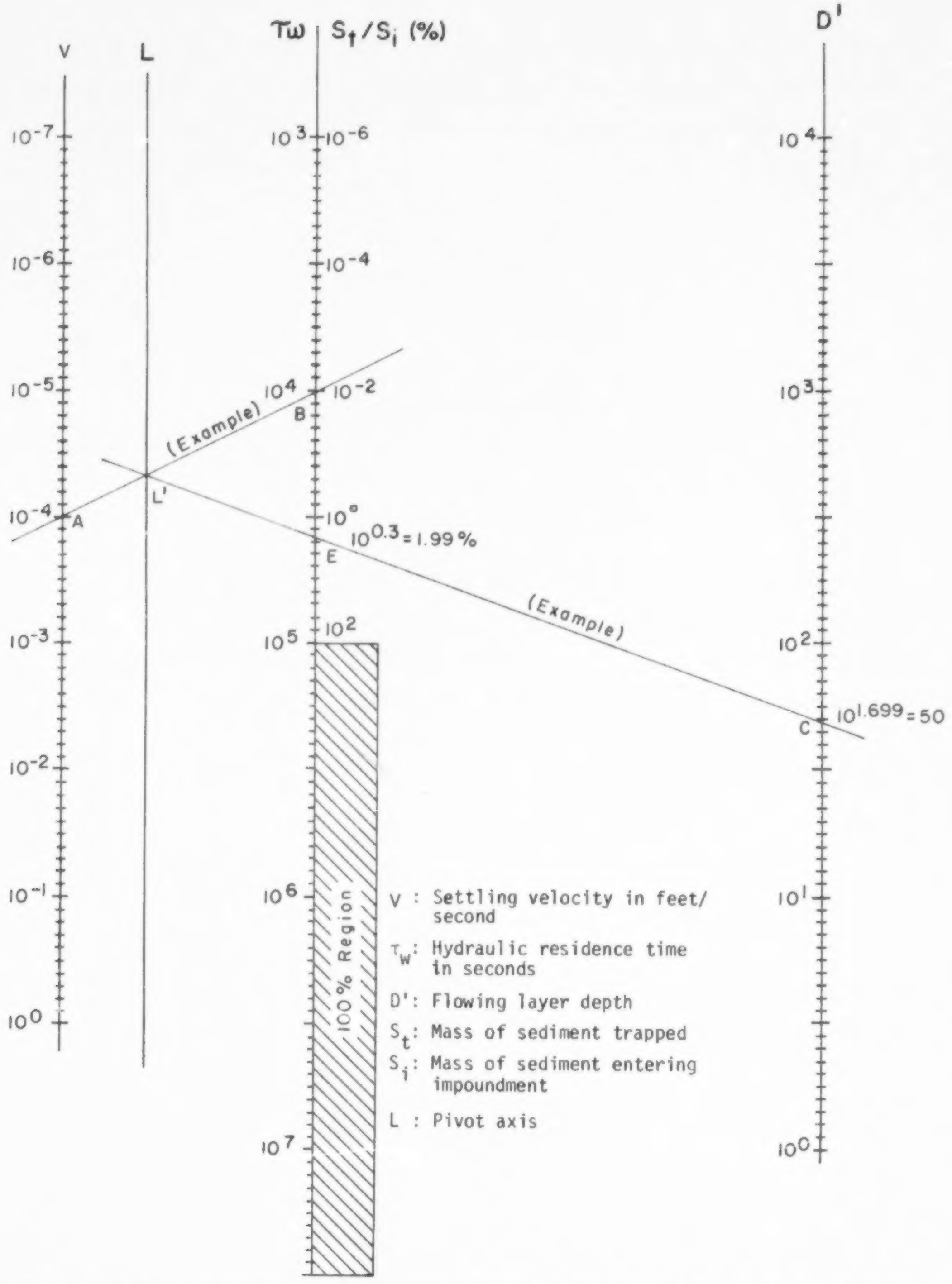


FIGURE V-22 NOMOGRAPH FOR ESTIMATING SEDIMENT TRAP EFFICIENCY

Although it is not specified in Table V-6, the inflow channel depth at the entrance to Upper Lake is 3 feet. The discharge channel depth is 10 feet. Assuming "laminar" flow with minimal vertical components, for clay:

$$\tau_w = \frac{[(T_w \times v) + D'' - D]}{D''}$$

$$P = \frac{[(1.6\text{x}10^4\text{x}9.3\text{x}10^{-5}) + 3 - 10]}{3}$$

$$P = -5.5$$

The negative value implies that the proportion settling out is virtually zero. Thus the clay will to a large extent pass through Upper Lake. However, τ_w for this example is very small (4.5 hours). Many impoundments will have substantially larger values.

For the sand,

$$P = \frac{[(1.6\text{x}10^4\text{x}7\text{x}10^{-2}) + 3 - 10]}{3}$$

$$P = 371$$

All of the sand will clearly be retained. Note that a clay or very fine silt of $V_{max} = 5\text{x}10^{-4}$ ft sec^{-1} would be only partially trapped.

$$P = \frac{[(1.6\text{x}10^4\text{x}5\text{x}10^{-4}) + 3 - 10]}{3}$$

$$P = 0.33$$

Thus about one-third of this sediment loading would be retained. Note that if D is large, trap efficiency drops using this algorithm. For the silt, a discharge channel depth (at the outflow from Upper Lake) of 11 feet rather than 10 would give

$$P = \frac{[(1.6\text{x}10^4\text{x}5\text{x}10^{-4}) + 3 - 11]}{3} = 0$$

Thus with D=11, all silt exits the impoundment. If D is only 9 feet, then

$$P = \frac{[(1.6\text{x}10^4\text{x}5\text{x}10^{-4}) + 3 - 9]}{3} = .66$$

Two-thirds of the silt is retained. Remember that P represents a mean value. Clearly during some periods none of the silt will be retained (due to turbulence, higher velocities) while during other periods, all of the silt will be trapped. The key here is the word "mean."

If the impoundment is assumed to be vertically mixed (case B), compute the mean depth $\bar{D}$

$$\bar{D} = \sum_{i=1}^{n} D_i/n$$

where

n = the number of cross-sections

D_i = depth at the ith cross-section

For Upper Lake,

$$\bar{D} = 6.7 = D'$$

Then

$$P = \frac{v\ \tau_w}{D'}$$

For the clay,

$$P = \frac{9.3\times10^{-5}\times1.6\times10^{4}}{6.7} = 0.22$$

About one-fourth of the clay is retained.

For the sand,

$$P = \frac{7\times10^{-2}\times1.6\times10^{4}}{6.7} = 167$$

All of the sand will be trapped within about 1/167 times the length of the lake. If the daily influent loading of sand is one ton, while the loading of clay is fifteen tons, then the daily accumulation will be one ton of sand and 0.22 x 15 = 3.3 tons of clay.

Finally, as an example of use of Figures V-21 and V-22, assume that the sediment loading consists primarily of silt particles in the size range of .002mm diameter, and that the water temperature is 5^{o}C. Further, assume τ_w has been estimated as 2.77 days (10^4 seconds), and that D'=50 feet. From Figure V-21, the settling velocity is about 1×10^{-4} feet per second.

In Figure V-22, draw a line from 10^{-4} on the V axis to 10^4 on the τ_w axis. The point of intersection with axis L is L'. Next, compute $\log_{10}50=1.699$. Draw a line from this point on the D' axis to L'. Where this line crosses the S_t/S_i (%) axis gives the log of the percent of the sediment trapped. This is $10^{0.3}=1.99\approx2\%$.

END OF EXAMPLE V-9

5.4 EUTROPHICATION AND CONTROL

5.4.1 Introduction

The presence of nutrients in an impoundment generally favors plant growth. Depending upon antecedent conditions, the relative abundance of nitrogen, phosphorus, light, and heat, and the status of a number of other physical and chemical variables, the predominant forms may be diatoms, other microscopic or macroscopic algae, or bottom-rooted or free-floating macrophytes. The quantity of plant matter present in an impoundment is important for several reasons. First, plant cells produce oxygen during photosynthesis, thereby providing an important source of dissolved oxygen to the water column. During the sunlight hours plant cells also consume oxygen through the process of respiration. Respiration occurs along with photosynthesis during the day, but also occurs at night. Oxygen consumed at night may be considerable, not only because it serves to sustain the plant cells, but because the cells actively perform various vital metabolic functions in the dark.

Plant growth within an impoundment is also important because plant biomass is a major source of nutrition for indigenous fauna, and the growth of plants constitutes what is called "primary production." The stored energy and nutrients provide food for various grazers higher in the food chain, either through direct consumption of living plant tissue by fishes and zooplankton or through consumption of detritus by fishes, microorganisms, and zooplankton. The grazers, in turn, provide food for predatory fishes, mammals, insects, and other higher forms.

Finally, plant development in impoundments is important because it tends to accelerate impoundment aging. As plants grow, organic matter and sediment accumulate. As the impoundment fills with rock fragments, soil, and plant detritus, an excellent substrate forms upon which more suspended matter may be trapped and which may ultimately support the growth of higher plants and trees. The gradual filling in of an impoundment in this way reduces its usefulness, and may finally eliminate the impoundment completely.

5.4.2 Nutrients, Eutrophy, and Algal Growth

Eutrophy means literally a state of good nutrition. Plants require a number of nutrients, but to vastly different degrees. Some nutrients, such as carbon, nitrogen, potassium, and phosphorus, are needed in large quantity. These are termed macronutrients. The micronutrients, e.g. iron, cobalt, manganese, zinc, and copper, are needed in very small amounts. In nature, the micronutrients, carbon, and potassium are usually in adequate supply (although not always), while nitrogen and phosphorus are commonly growth limiting.

Nitrogen, particularly as nitrate and ammonium ions, is available to water-borne plant cells to be used in synthesis of proteins, chlorophyll a, and plant hormones. Each of these substances is vital for plant survival.

Phosphorus, an element found in a number of metabolic cofactors, is also necessary for plant nutrition. The biosynthesis and functioning of various biochemical cofactors rely on the availability of phosphorus, and these cofactors lie at the very foundation of plant cell metabolism. Without adequate phosphorus, plant cells cannot grow.

Since nitrogen and phosphorus are commonly in limited supply, many impoundments tend inherently to be clear and essentially free of clogging algae and vascular plants. Because of society's ever-increasing size and need for food, chemical sources of nitrogen and phosphorus are synthesized and spread over vast tracts of farmland. Stormwater washes off these nutrients, which then flow through streams and into natural and artificial impoundments. Also, excessive nutrients occur in wastewaters from municipalities and industry. Due to the fact that many impoundments have very low flow velocities, impoundments represent excellent biological culturing vessels, and often become choked with plant life when nutrients increase.

Since a plant cell has at any point in time a specific need for nitrogen and for phosphorus, one or the other or both may limit cell growth or replication. Where nitrogen is the nutrient that restricts the rate of plant growth, that is, where all other nutrients and factors are present in excess, we say that nitrogen is growth limiting. In general, N:P ratios in the range of 5 to 10 by mass are usually associated with plant growth being neither nitrogen nor phosphorus limited. However, in this range, plant growth may well be limited by N and P collectively. Where the ratio is greater than 10, phosphorus tends to be limiting, and for ratios below 5, nitrogen tends to be limiting (Chiaudani, et al., 1974).

In addition to nitrogen and phosphorus, any necessary nutrient or physical condition may limit plant growth. For example, in highly nutritious (eutrophic) waters, algal biomass may increase until light cannot penetrate, and light is then limiting. At such a point, a dynamic equilibrium exists in which algal cells are consumed, settle or lyse (break) at the same rate as new cells are produced.

To summarize, the process of eutrophication (or fertilization) is enrichment of a lake with nutrients, particularly nitrogen and phosphorus. However, the problem of eutrophication resulting from increased plant biomass caused by enrichment will be discussed. Some of the problems of predicting algae and the screening method will be developed for screening purposes, a nutrient approach will be taken so that control measures can be evaluated and then, plant biomass (algal blooms and macrophytes), will be estimated to provide a relationship with the problem of eutrophication.

5.4.3 Predicting Algal Concentrations

Predicting algal blooms or predominance of macrophytes using a mechanistic approach can be a very complex problem, and most methods are not suited to a simple hand calculation technique. Some relationships regarding algal productivity have been derived, however, which permit an evaluation of the eutrophic state of an impoundment. Because the methods permit algal biomass to be estimated with relatively little, easily obtained data, and because algae are very important in assessing impoundment water quality, these techniques are useful here. The methods presented below are based upon the fact that in most cases (perhaps 60 percent) phosphorus is the biomass limiting nutrient (EPA, 1975). One such approach has been developed by Vollenweider (Vollenweider, 1976; Lorenzen, 1976). It may be used to predict the degree of impoundment eutrophication as a function of areal phosphorus loading. It does not, however, permit direct estimates of algal biomass to be made.

Before considering application of any of the methods to assess eutrophication, it is important to examine the nitrogen to phosphorus ratio. This indicates whether any of the methods presented below is likely to give realistic results.

5.4.3.1 Nutrient Limitation

Generally, an average algal cell has an elemental composition for the macronutrients of $C_{106} N_{16} P_1$. With 16 atoms of nitrogen for each atom of phosphorus, the average composition by weight is 6.3 percent nitrogen and 0.87 percent phosphorus or an N/P ratio of 7.2/1. For N/P ratios greater than 7.2, phosphorus would be less available for growth ("limiting") and less than 7.2, nitrogen would be limiting. In practice, values of less than 5 are considered nitrogen limiting, greater than 10 are phosphorus limiting, and between 5 and 10, both are limiting.

In many cases of eutrophic lakes, nitrogen is not limiting because of the process of nitrogen fixation. Some blue-green algae, a particularly noxious type of algae, have enzymatic processes for the biochemical conversion of dissolved elemental nitrogen into reduced nitrogen (amine groups) suitable for growth and metabolism. Special cells called heterocysts perform this process and only appear when nitrogen is limiting. It can be argued that in general nitrogen is not limiting and a "worst case" analysis can be made for a screening approach using phosphorus. However, the chlorophyll produced is affected by the N/P ratio as are the algal species.

5.4.3.2 Nutrient Availability

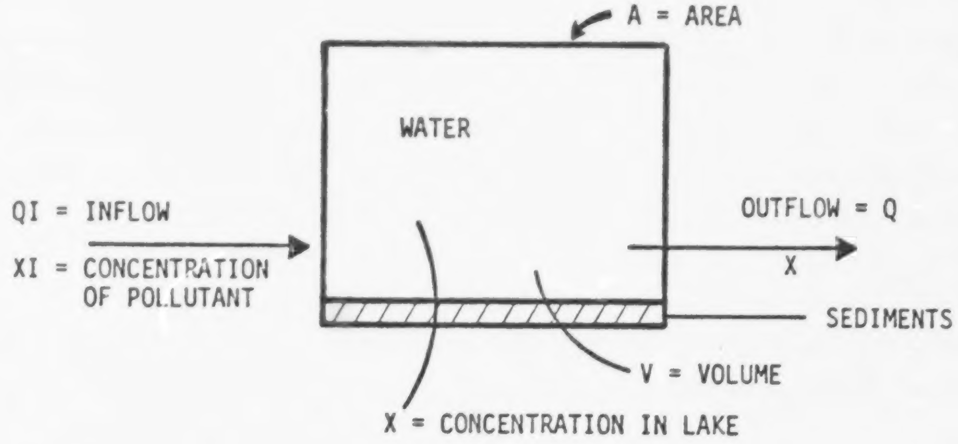
Availability of nutrients is also important. Particulate nitrogen and phosphorus in the inflowing tributaries generally settle and can therefore be considered unavailable. Few estimates of bioavailable nutrients have been made and only for phosphorus. Cowen and Lee (1976) indicated that 30 percent or less of urban runoff phosphorus was available to algae while Dorich et al. (1980) found a value of 20 to 30 percent for sediment bound phosphorus (as would occur in rural runoff). It appears that a fraction of 0.3 would provide a conservative estimate of bioavailable phosphorus in the absence of actual measurements.

5.4.4 Mass Balance of Phosphorus

A material entering a lake or impoundment will partition between the aqueous and solid phases. The solid phase can settle and become bottom sediment or outflow can remove suspended and aqueous phase material. A diagramatic presentation of this concept is shown in Figure V-23. The concentration of the material can be calculated very simply after making several assumptions: the lake is completely mixed, the lake is at steady state and inflowing water equals outflow, and the annual average rates are constant. Although these assumptions are not met entirely for phosphorus, they are satisfied well enough to meet requirements for a screening analysis of eutrophication. Based on its historical development the eutrophication screening methods are termed the "Vollenweider Relationship."

As shown in Figure V-23, any of three different forms of the steady state equation can be used to predict phosphorus concentrations in lakes. Each form may be more or less suitable for a specific data set. The important variables are the hydraulic flushing or dilution rate (Q/V, inverse of residence time), lake volume to area ratio (V/A, equals mean depth), phosphorus in the influent (PI), and the net rate of removal (K).

The variables Q, V, A must be determined from other data. The influent phosphorus can be based on measurements or estimated from calculations performed as in Chapter 3 and including any municipal and industrial



For Example - Phosphorus, P = X

LOADING

$$Lp = QI \cdot PI / A, \text{ mg/m}^2 \text{ year}$$

MASS BALANCE

Assumptions: completely mixed, steady state, $Q \cong QI$, annual average rates are constant

Definitions: Mean depth, $\bar{Z} = V/A$; hydraulic flushing or dilution rate, $D = Q/V$; hydraulic loading, $q_s = Q/A$; $M = QI \cdot PI$; K = net rate of solid phase removal and release (proportional to P), typically negative when averaged over the annual cycle.

$$\frac{dP}{dt} = \frac{Q \cdot PI}{V} - \frac{Q \cdot P}{V} - KP = 0$$

Solving for P,

$$P = \frac{D \cdot PI}{D + K} \qquad \text{(Mass Balance Form)}$$

$$P = \frac{M}{Q} \left(\frac{D}{D + K}\right) \qquad \text{(Mass Inflow Form)}$$

$$P = \frac{Lp}{\bar{Z}\,(D + K)} \qquad \text{(Loading Form)}$$

Figure V-23 Formulations for Evaluating Management Options for Pollutants in Lakes and Reservoirs

effluents. Generally, effluents are considered totally available for growth. Nonpoint sources should be assessed as 100 percent available and as 30 percent available to provide limits for screening purposes.

Estimation of the net rate of removal (K) is not as clear. Jones & Bachmann (1976) estimated that K=0.65 by least squares fitting of data for 143 lakes.

Vollenweider (1976) and Larsen and Mercier (1976) independently estimated the net rate of removal as a function of dilution rate:

$$K = \sqrt{D}$$

This approach is best used for screening. Also the value of K can be estimated from the ratio (R) of the measured mass phosphorus retained (in-out) and the mass inflow:

$$R = \frac{QI \cdot PI - Q \cdot P}{QI \cdot PI} \cong \frac{PI - P}{PI}$$

$$K = \frac{Lp}{P \cdot \bar{Z}} (R)$$

To assess the placement of a specific lake relative to a set of lakes, phosphorus loading (PL) is graphed as a function of hydraulic loading (q) (Figure V-24). The data for 34 U.S. surface waters are shown. (Some lakes occur more than once because of multi-year studies.)

EXAMPLE V-10

Big Reservoir and
The Vollenweider Relationship

To use the Vollenweider relationship or phosphorus loading, data on long-term phosphorus loading rates must beavailable. It is also important that the rates represent average loading conditions over time because transient phosphorus loading pulses will give misleading results. Big Reservoir is a squarish reservoir and has the following characteristics:

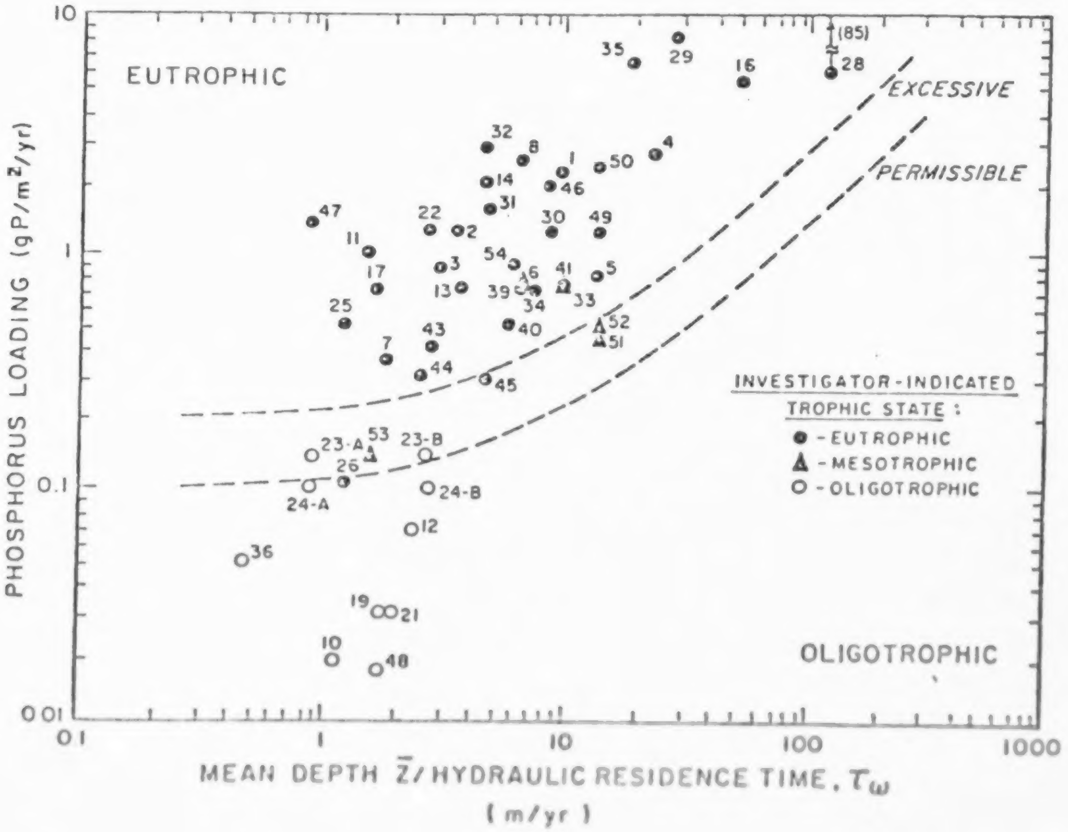


FIGURE V-24 US OECD DATA APPLIED TO VOLLENWEIDER (1976) PHOSPHORUS LOADING AND MEAN DEPTH/HYDRAULIC RESIDENCE TIME RELATIONSHIP (TAKEN FROM RAST AND LEE, 1978)

Big Reservoir

Available Data (all values are means):

Length	2.0 mi	= 3.22 km
Width	5. mi	= .805 km
Depth (Z)	200 ft	= 20 m
Inflow (Q)	50 cfs	= 1.42 cms
Total phosphorus concentration in water column		0.482 ppm
Total nitrogen concentration in water column		2.2 ppm
Total phosphorus concentration in the inflow		1.0 ppm

In order to apply the plot in Figure V-24, the first step is to make as certain as possible that algal growth is phosphorus limited. In this case, the weight to weight N:P ratio is 2.2/.48 = 4.6. Presumably, algal growth in Big Reservoir is not phosphorus limited, and the Vollenweider relationship for phosphorus is not a good one to use. In this case a rigorous model should be used. If nitrogen fixation is observed to occur (heterocystous blue-green algae), an estimate of the potential problem can be obtained by assuming phosphorus to be limiting:

$$V = 3220\text{m} \cdot 805\text{m} \cdot 20\text{m} = 51.8 \text{ million m}^3$$

$$D = \frac{1.42 \text{ m}^3}{\text{sec } 51.8\text{Mm}^3} \cdot \frac{86400 \text{ sec}}{\text{day}} \cdot \frac{365 \text{ day}}{\text{yr}} \cdot \frac{.865}{\text{yr}}$$

$$\tau_w = 1.16 \text{ years}$$

$$K = VD = 0.93$$

$$P = \frac{D \cdot PI}{D + K} = 0.482 \text{ mg/l}$$

$$Lp = Q \cdot PI/A = 17.3 \text{ g/m}^2 \text{ yr}$$

$$q_s = Q/A = \bar{\bar{Z}}/\tau w = 20/1.16 = 17.2 \text{ m/yr}$$

Plotting Lp and q_s on Figure V-24 shows that the reservoir could be extremely eutrophic.

END OF EXAMPLE V-10

EXAMPLE V-11

Bigger Reservoir and The Vollenweider Relationship

The physical characteristics of Bigger Reservoir are:

Bigger Reservoir

Available Data (all values are means):

Length	20 mi	= 32.2 km
Width	10 mi	= 16.1 km
Depth ($\bar{Z}$)	200 ft	= 61 m
Inflow (Q)	500 cfs	
Total phosphorus concentration in inflow		0.8 ppm
Total nitrogen concentration in inflow		10.6 ppm

As in the preceding example, first determine whether phosphorus is likely to be growth limiting. Since data are available only for influent water, and since no additional data are available on impoundment water quality, N:P for influent water will be used.

$$N{:}P = 10.6/0.8 = 13.25$$

Thus algal growth in Bigger Reservoir is probably phosphorus limited. Compute the approximate surface area, volume and the hydraulic residence time.

$$\text{Volume } (V) = 20 \text{ mi} \times 10 \text{ mi} \times 200 \text{ ft} \times 5280^2 =$$
$$1.12 \times 10^{12} \text{ft}^3 = 3.16 \times 10^{10} \text{m}^3$$

Hydraulic residence time (τ_w) = V/Q =

$$1.12 \times 10^{12} \text{ft}^3 / 500 \text{ ft}^3 \text{sec}^{-1} = 2.24 \times 10^9 \text{sec} = 71 \text{ yr}$$

Surface area (A) = 20 mi x 10 mi x 5280^2 =

$$5.57 \times 10^9 \text{ft}^2 = 5.18 \times 10^8 \text{m}^2$$

Next, compute q_s

$$q_s = \bar{Z}/\tau_w$$

$$q_s = 61 \text{ m}/71 \text{ yr} = 0.86 \text{ m yr}^{-1}$$

Compute annual inflow, Q_y

$$Q_y = Q \times 3.15 \times 10^7 \text{ sec yr}^{-1}$$

$$Q_y = 1.58 \times 10^{10} \text{ft}^3 \text{ yr}^{-1}$$

Phosphorus concentration in the inflow is 0.8 ppm or 0.8 mg/l. Loading (Lp) in grams per square meter per year is computed from the phosphorus concentration, in mg/l:

$$\text{Lp} = \frac{28.31\ell}{\text{ft}^3} \times \frac{1 \text{ g}}{1000\text{mg}} \times \frac{0.8 \text{ mg}}{\ell} \times \frac{1}{5.18 \times 10^8 \text{M}^2} \times 1.58 \times 10^{10} \frac{\text{ft}^3}{\text{yr}}$$

$$\text{Lp} = 0.70 \text{ gm}^{-2} \text{yr}^{-1}$$

Now, referring to the plot in Figure V-23, we would expect that Bigger Reservoir is eutrophic, possibly with severe summer algal blooms.

END OF EXAMPLE V-11

EXAMPLE V-12

The Vollenweider Relationship
Using Monthly Inflow Quality Data

Is Frog Lake eutrophic? Frog Lake's physical characteristics are as shown below:

Frog Lake

Available Data:

Mean length	2 mi
Mean width	1/2 mi
Mean depth	25 ft

Available Inflow Water Quality Data:

Month	Q (monthly mean, cfs) 1972	Q (monthly mean, cfs) 1974	Total P (mg/l) 1972	Total P (mg/l) 1974	Inorganic N (mg/l) 1972	Inorganic N (mg/l) 1974
October	50	65	0.1	0.08	7.2	6.0
November	80	90	0.02	0.02	6.3	2.4
December	40	40	0.03	0.04	3.1	1.5
January	-	-	-	-	-	-
February	-	-	-	-	-	-
March	60	58	0.01	0.02	2.0	1.9
April	80	80	0.01	0.01	2.3	0.50
May	75	76	0.04	0.05	0.55	0.52
June	40	70	0.03	0.08	1.20	1.35
July	-	25	-	0.11	-	2.01
August	38	20	0.09	0.04	3.50	1.29
September	38	25	0.06	0.06	2.80	1.00

First, estimate the mean annual flow and the hydraulic residence time. To compute mean annual flow,

$$Q = \left(\sum_{i=1}^{y} \sum_{j=1}^{n_i} Q_{i,j} \right) / \sum_{i=1}^{y} n_i$$

where

$Q_{i,j}$ = the individual flow measurements
y = the number of years of data
n_i = the number of observations per year

$$Q = 1050/19 = 55.3 \text{ cfs} = 1.75 \times 10^9 \text{ ft}^3/\text{yr}$$

Now estimate the volume, surface area, hydraulic residence time, and q_s

$$V = 2 \text{ mi} \times 1/2 \text{ mi} \times 25 \text{ ft} \times 5280^2 = 6.97 \times 10^8 \text{ft}^3 = 1.98 \times 10^7 \text{m}^3$$

$$A = 2 \text{ mi} \times 1/2 \text{ mi} \times 5280^2 = 2.79 \times 10^7 \text{ft}^2 = 2.59 \times 10^6 \text{m}^2$$

$$\tau_w = V/Q = 6.97 \times 10^8 \text{ft}^3/55.3 \text{ cfs} = 1.26 \times 10^7 \text{sec} = 0.4 \text{ yr}$$

$$q_s = 25/0.4 = 62.5$$

Next, calculate the weighted mean inflow phosphorus and nitrogen concentrations $\bar{P}$ and $\bar{N}$ as follows:

$$\bar{P} \text{ (or } \bar{N}) = \left(\sum_{i=1}^{y} \sum_{j=1}^{n_i} Q_{i,j} \times C_{i,j} \right) / \left(\sum_{i=1}^{y} \sum_{j=1}^{n_i} Q_{i,j} \right)$$

$$\bar{P} = 43.86/1050 = 0.042 \text{ ppm}$$

$$\bar{N} = 2671.902/1050 = 2.54 \text{ ppm}$$

The N:P ratio in the inflows is 60. Therefore if one of the two is growth limiting, it is probably phosphorus. Compute the phosphorus loading, Lp.

$$L_p = \frac{23.31\ell}{ft^3} \times \frac{1\ g}{1000\ mg} \times \frac{0.042\ mg}{\ell} \times \frac{1}{2.59 \times 10^6 m^2} \times \frac{1.75 \times 10^9 ft^3}{yr}$$

$$Lp = 0.80$$

Now, referring to the plot in Figure V- 23 with Lp = 0.80 and q_s = 62.5, the impoundment is well into the oligotrophic region.

END OF EXAMPLE V-12

5.4.5 Phosphorus Levels in Predicting Algal Productivity and Biomass

Another technique, which is also based upon phosphorus loading, may be even more useful than the Vollenweider relationship because it permits summer chlorophyll a concentrations to be estimated rather than general impoundment trophic status. The method has been advanced by several researchers including Sakamoto (1966), Lund (1971), Dillon (1974), and Dillon and Rigler (1975). Briefly, the method relates mean summer chlorophyll a concentrations to spring mean total phosphorus. As shown in Figure V-25, the relationship is highly correlated, and a regression of the log of summer mean chlorophyll a on the log of spring mean phosphorus is linear. Using a least squares method gives the equation of the line as (Lorenzen, 1978):

$$\log(\text{chl } \underline{a}) = 1.5 \log(P) - 1.1 \qquad \text{(V-15)}$$

or

$$\text{chl } \underline{a} = 0.08(P)^{1.5} \quad P \leq 250\ m/m^3 = 0.25\ ppm \qquad \text{(V-16)}$$

Figure V-26 shows a plot of maximal primary production in terms of milligrams carbon incorporated in algae per square meter per day as a function of phosphate phosphorus levels. As was the case with predicting chlorophyll a concentrations, the relationship appears to be reasonably robust and therefore useful.

Because dried algae contain very roughly 3 percent chlorophyll a (J.A. Elder, pers. comm., 1977), dry algal biomass may be estimated from chlorophyll a concentration by multiplying by thirty-three. Similarly,

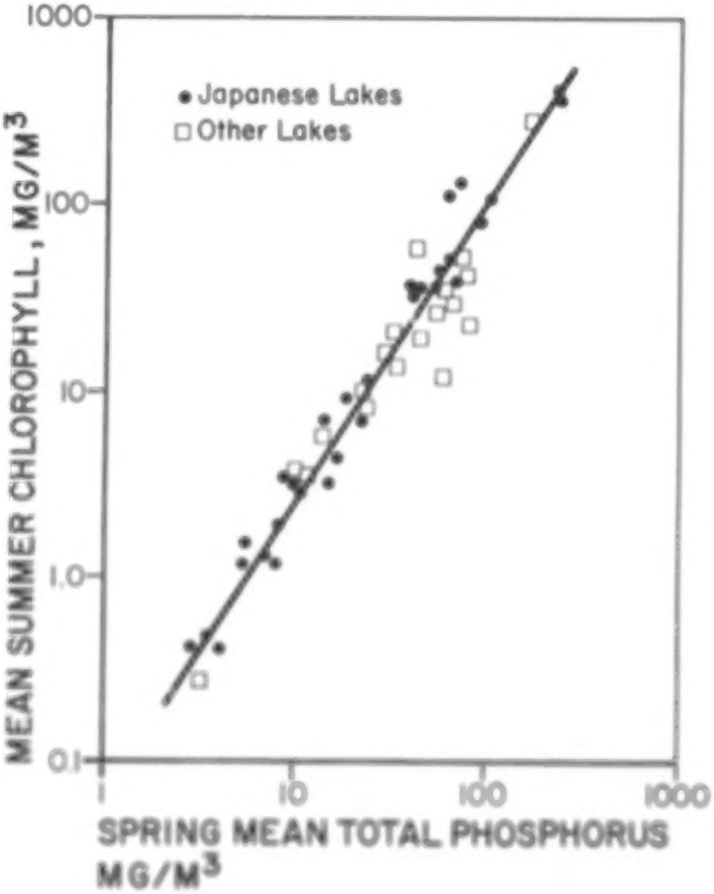


FIGURE V-25 RELATIONSHIP BETWEEN SUMMER CHLOROPHYLL AND SPRING PHOSPHORUS (FROM LORENZEN, UNPUBLISHED)

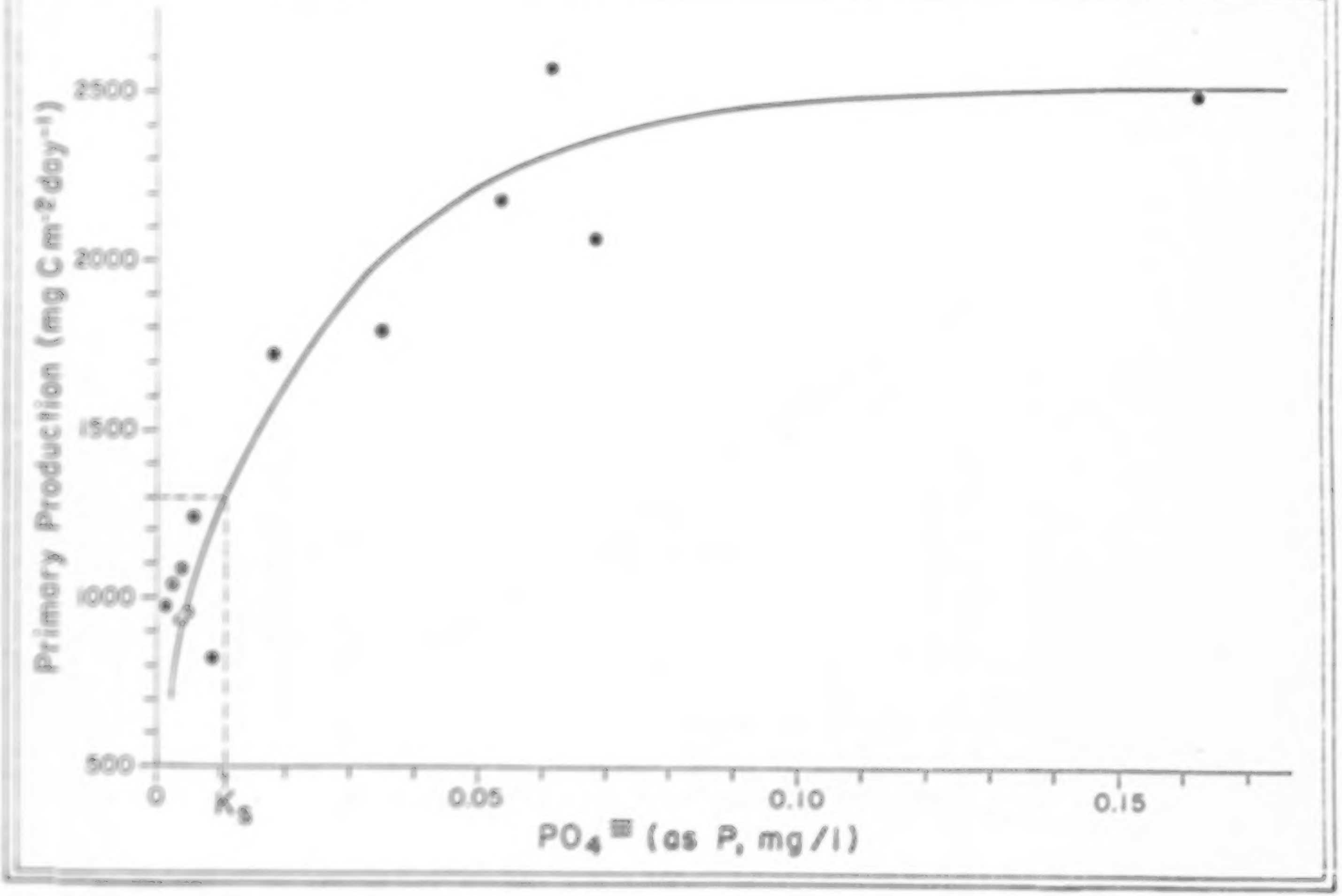


FIGURE V-26 MAXIMAL PRIMARY PRODUCTIVITY AS A FUNCTION OF PHOSPHATE CONCENTRATION (AFTER CHIAUDANI, ET AL., 1974)

carbon productivity, as in the plot in Figure V-26, may be converted to total algal biomass. Since approximate analysis of dried algae has been determined as (Stumm and Morgan, 1970):

$$C_{106}H_{263}O_{110}N_{16}P_1$$

the gravimetric factor is $\frac{3550}{1271} = 2.8$. Thus, maximal carbon productivity may be multiplied by 2.8 to give a rough estimate of maximal algal biomass productivity.

The user should bear in mind that applying this technique can only lead to rough estimates. If it is desired to predict biomass or productivity with accuracy, more sophisticated approaches may be necessary.

EXAMPLE V-13

Spring Phosphorus and Summer Chlorophyll a

Lake Sara mean spring total phosphorus concentration = .03 mg/l = 30 mg/m^{-3}

$$\text{chl } \underline{a} = 0.08(P)^{1.5}$$
$$\text{chl } \underline{a} = 13.1 \text{ mg/m}^3$$
$$\text{algal dry biomass} \cong 13.1 \times 33 = 430 \text{ mg/m}^3$$

Maximal carbon productivity in the impoundment may be estimated from the curve in Figure V-26 to be about 1950 mgCm^{-2}day^{-1} or about 5460 mg dry algal biomass m^{-2}day^{-1}.

Observe that the two methods may lead to contradictions. In this case, if Lake Sara is 5 meters deep, the concentration is 5460/5 = 1092 mg/m^3. This does not compare well with the 430 mg/m^3 value just computed, and the discrepancy reflects one inadequacy in usage of the Chiaudani curve, namely, that it really does not permit estimates of concentration to be made. The discrepancy also reaffirms the importance of applying good judgment in evaluating estimates and in using more than one technique.

END OF EXAMPLE V-13

In the absence of measured data, the in-lake concentration (P) can be computed based on the various point and nonpoint loadings (n):

$$Lp = \sum_{i=1}^{n} Q_i PI_i$$

$$P = \frac{Lp}{\bar{Z}\ (D+K)}$$

Then chlorophyll a can be estimated as shown in the previous paragraphs.

5.4.6 Restoration Measures

Control of eutrophication in lakes can be evaluated by a variety of approaches (Table V-9). Some methods are directed at external sources (PI) and others at in-lake sources (K). Changes in volume (V) and inflow (Q) obviously will affect predicted results. For example, dredging will decrease the return of phosphorus for the sediments (i.e. increase K) and increase the volume (i.e. decrease D). If the input concentration (PI) is the initial variable, then source controls should be investigated. If internal sources are involved, then in-lake controls should be evaluated. In many lakes, both source and in-lake controls will be needed.

Problem treatment is directed at the productivity directly. These controls are often the only alternative for many lake situations. These methods are evaluated only in a qualitative way.

TABLE V-9

CLASSIFICATION OF LAKE RESTORATION TECHNIQUES

I. Source Controls
   - A. Treatment of inflows
   - B. Diversion of inflows
   - C. Watershed management (land uses, practices, nonpoint source control, regulations and/or treatments).
   - D. Lake riparian regulation or modification
   - E. Product modification or regulation

II. In-Lake Controls
   - A. Dredging
   - B. Volume changes other than by dredging or compaction of sediments
   - C. Nutrient inactivation
   - D. Dilution/Flushing
   - E. Flow adjustment .
   - F. Sediment exposure and dessication
   - G. Lake bottom sealing
   - H. In-lake sediment leaching
   - I. Shoreline modification
   - J. Riparian treatment of lake water
   - K. Selective discharge

III. Problem Treatment (directed at biological consequences of lake condition)
   - A. Physical techniques (harvesting, water level fluctutations, habitat manipulations)
   - B. Chemical (algicides, herbicides, pesticides)
   - C. Biological (predator-prey manipulations, pathological reactions).
   - D. Mixing (aeration, mechanical pumps, lake bottom modification)
   - E. Aeration (add DO; e.g. hypolimnetic aeration)

5.4.7 Water Column Phosphorus Concentrations

The relationships described in 5.4.5 for predicting algal biomass are predicated on phosphorus levels within the impoundment. A more precise mechanism for estimating phosphorus lake concentrations based on interactions between bottom sediments and overlying water has been developed.

Lorenzen, et al. (1976) developed a phosphorus budget model (Figure V-27) which may be used to estimate water column and sediment bound phosphorus in a fully mixed system. A mass balance on both sediment and water column phosphorus concentrations yields the coupled differential equations:

$$\frac{dC_w}{dt} = \frac{M}{V} + \frac{K_2 A C_s}{V} - \frac{K_1 A C_w}{V} - \frac{C_w Q}{V} \qquad \text{(V-17)}$$

$$\frac{dC_s}{dt} = \frac{K_1 A C_w}{V_s} - \frac{K_2 A C_s}{V_s} - \frac{K_1 K_3 A C_w}{V_s} \qquad \text{(V-18)}$$

C_w = average annual total phosphorus concentration in water column (g/m^3)

C_s = total exchangeable phosphorus concentration in the sediments (g/m^3)

M = total annual phosphorus loading (g/yr)

V = lake volume (m^3)

V_s = sediment volume (m^3)

A = lake surface area (m^2) - sediment area (m^2)

Q = annual outflow (m^3/yr)

K_1 = specific rate of phosphorus transfer to the sediments (m/yr)

K_2 = specific rate of phosphorus transfer from the sediments (m/yr)

K_3 = fraction of total phosphorus input to sediment that is unavailable for the exchange process

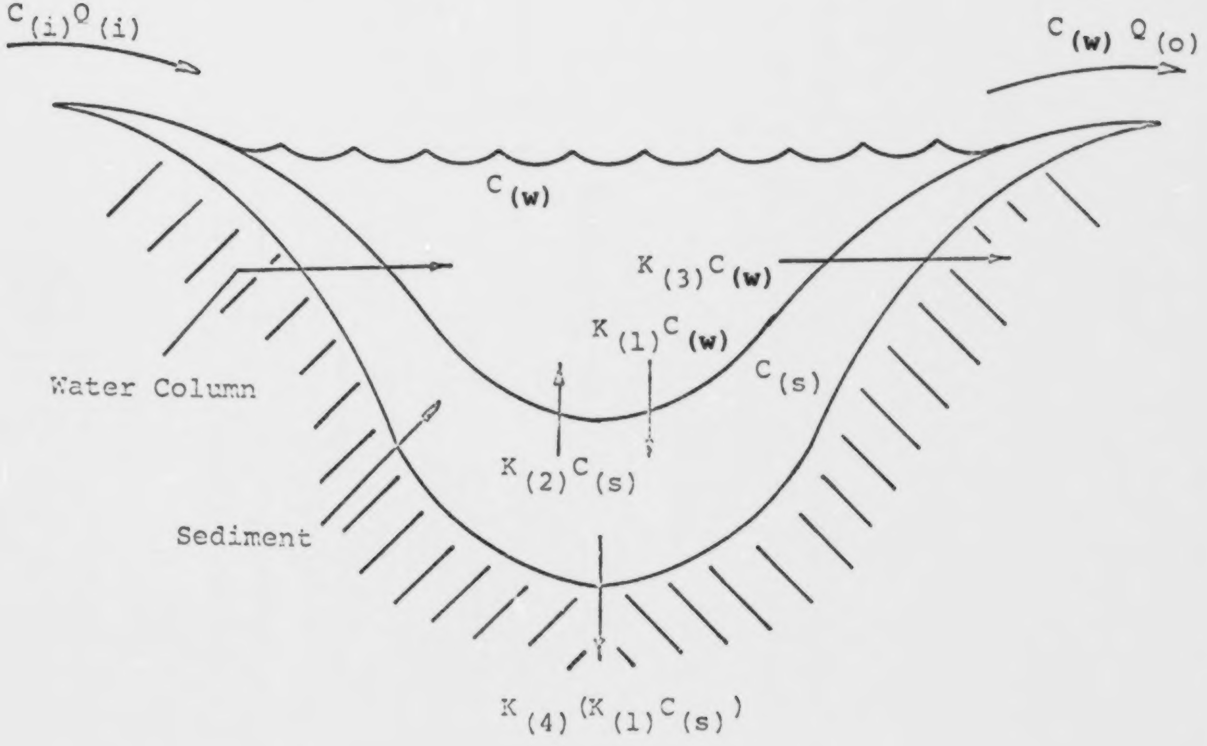


FIGURE V-27 CONCEPTUALIZATION OF PHOSPHORUS BUDGET MODELING (LORENZEN ET AL., 1976)

When the differential equations relating water column phosphorus to the various controlling phenomena are solved analytically, the following equation results for steady-state water column phosphorus concentration:

$$C_w = \frac{C_{in}}{1 + \frac{K_1 K_3 A}{Q}} \qquad \text{(V-19)}$$

or

$$C_w = \frac{M}{Q + K_1 K_3 A} \qquad \text{(V-20)}$$

where

C_w = steady-state water column phosphorus concentration in ppm
C_{in} = steady-state influent phosphorus concentration in ppm

The steady-state sediment phosphorus concentration is then given by:

$$C_s = \frac{C_{in} K_1 (1 - K_3)}{K_2 (1 + (K_1 K_3 A/Q))} \qquad \text{(V-21)}$$

It is important to observe that these relationships are valid only for steady-state conditions. Where phosphorus loading is changing with time, where sediment deposition or physical characteristics are changing, or where there are long-term changes in physical conditions, the steady-state solutions are not applicable.

Lorenzen applied the model to Lake Washington data and obtained very good results. With their data set, the most satisfactory coefficients had the following values:

K_1 = 43 m/yr
K_2 = 0.0014 m/yr
K_3 = 0.5

It should be recognized, however, that this model is relatively untested and that coefficient values for other impoundments will vary from those cited here.

EXAMPLE V-14

A Comprehensive Example
Impoundment Water Column Phosphorus

What will be the steady-state concentration of phosphorus in the water column of Lake Jones following diversion of flow? How will this affect algal abundance?

Lake Jones:

Area, A.	20 miles^2 = 5.6×10^8ft^2 = 5.2×10^7m^2
Volume, V.	3.08×10^{11}ft^3 = 8.73×10^9m^3

Available Data (prior to diversion):

Inflows:

		Mean Annual Flow, cfs	Mean P, mg/l
1.	Janes River	75	.15
2.	Jennies River	22	.07
3.	Johns Creek	5	.21
4.	Direct stormwater influx (nominal, may be disregarded)		

The diversion, which is for irrigation purposes, has resulted in lowering the mean annual inflow from Jennies River to 1 cfs with an average annual phosphorus concentration of 0.01 mg/l. Additionally, there is a reduction of flow in Janes River to 55 cfs.

To apply the Vollenweider relationship, first to the prediversion status of Lake Jones, compute q_s:

$$q_s = \frac{\bar{Z}}{\tau_w}$$

$$\bar{Z} = \frac{8.73\times10^9\,\mathrm{m}^3}{5.2\times10^7\,\mathrm{m}^2} = 168\ \mathrm{m}$$

Based upon the conceptualization (see Figure V-27), it is reasonable that the coefficients interact. For example, K_1, the rate of phosphorus uptake by the sediment must be related to the rate of phosphorus release by the sediment. The model requires however, that the product K_1K_3 be constant. The value used by Lorenzen, et al. was 21.6. As they point out, the coefficients must satisfy certain conditions, specifically those established by the derived equations. The equations are:

$$C_w = \frac{M}{Q + K_1K_3A} \qquad \text{(V-22)}$$

and

$$\frac{C_w}{C_s} = \frac{K_2}{K_1(1-K_3)} \qquad \text{(V-23)}$$

From (V-22)

$$K_1K_3 = \frac{M-QC_w}{C_wA} \qquad \text{(V-24)}$$

Computation of K_1, therefore, requires a value for K_3. This coefficient, (K_3) unfortunately, is usually unavailable. It represents the fraction of phosphorus entering the sediment which is not available to return to the water column. Phenomena contributing to this are steady-state sediment accumulation, and steady-state chemical precipitation of phosphorus, such as with iron to form $Fe_3(PO_4)\cdot 8H_2O$ (vivianite). Lorenzen's value for Lake Washington was 50 percent. Because the fraction is likely to vary significantly from system to system and because the coefficient is difficult to evaluate, the planner is advised to use 30 percent as the lower limit, 50 percent as a probable value, and 70 percent as an upper limit for estimating sediment phosphorus content. The water column concentration is independent of changes in K_3 because the product of K_1 and K_3 is a constant.

Using Equation (V-24), K_3 uniquely defines K_1. Then, from Equation (V-23).

$$K_2 = \frac{C_wK_1(1-K_3)}{C_s}$$

K_2 is therefore also defined by fixing K_3, providing C_w and C_s are known.

$$M = \left[\left(\frac{75\text{ft}^3}{\text{Sec}} \times \frac{0.15\text{ mg}}{\ell}\right) + \left(\frac{22\text{ft}^3}{\text{Sec}} \times \frac{.07\text{ mg}}{\ell}\right) + \left(\frac{5\text{ft}^3}{\text{Sec}} \times \frac{.21\text{ mg}}{\ell}\right)\right]$$

$$\times \frac{28.31\ell}{\text{ft}} \times \frac{1\text{ g}}{1000\text{ mg}} \times \frac{3.16\text{x}10^7\text{sec}}{\text{yr}}$$

$$M = 1.24\text{x}10^7\text{ gP yr}$$

$$Q = \frac{(75+22+5)\text{ft}^3}{\text{sec}} \times \frac{3.16\text{x}10^7\text{ sec}}{\text{yr}} = \frac{3.22\text{x}10^9\text{ft}^3}{\text{yr}} = \frac{9.13\text{x}10^7\text{m}^3}{\text{yr}}$$

$$\tau_w = 8.73\text{x}10^9\text{ m}^3/9.13\text{x}10^7\text{m}^3\text{yr}^{-1} = 95.6\text{ yr}$$

$$q_s = 168/95.6 = 1.76\text{ m yr}^{-1}$$

Compute phosphorus loading:

$$Lp = \frac{M}{A}$$

$$Lp = \frac{1.24\text{x}10^7\text{ g yr}^{-1}}{5.2\text{x}10^7\text{ m}^2} = 0.24\text{ gm}^{-2}\text{yr}^{-1}$$

Referring to Figure V-24 with $q_s = 1.76$ and $Lp = 0.24$, one can see that this lake may have eutrophication problems under pre-diversion conditions.

After the diversion,

$$\tau_w = \frac{8.73\text{x}10^9\text{m}^3}{6.98\text{x}10^7\text{m}^3/\text{yr}} = 125\text{ yr}$$

Assuming the lake depth is not materially changed over the short term,

$$q_s = 168/125 = 1.34\ \frac{\text{m}}{\text{yr}}$$

For the new conditions,

$$M = 8.33 \times 10^6\text{ gP yr}^{-1}$$

$$Lp = \frac{8.33\text{x}10^6 \text{ g yr}^{-1}}{5.2\text{x}10^7 \text{ m}^2} = .16 \text{ gP/m}^2\text{yr}$$

Now, according to the Vollenweider plot (Figure V-24), this is in the region between "dangerous" and "permissible" - the mesotrophic region. Under the new circumstances, algal blooms are less likely than before the flow diversions were established, but blooms are by no means to be ruled out.

Turning now to an estimate of algal biomass under pre-diversion conditions, we must calculate the inlake concentration (P).

First, $D = 1/\tau w = 1/125 = 0.008; \quad K = \sqrt{D} = 0.09$

Since our data are already in the loading form:

$$P = \left(\frac{PL}{\bar{Z}}\right)\left(\frac{1}{D+K}\right)$$

$$= \left(\frac{0.24}{168}\right)\left(\frac{1}{0.008+0.09}\right) = 15 \text{ mg/m}^3$$

Based on chlorophyll a,

$$\text{chl } \underline{A} = 0.08(P)^{1.5}$$

$$\text{chl } \underline{A} = 0.08\ (15)^{1.5} = 4.6 \text{ mg/m}^3$$

Dry algal biomass - 4.6x33 = 150 mg/m^3

Under post-diversion conditions,

$$P = \left(\frac{0.16}{168}\right)\left(\frac{1}{0.008+0.09}\right) = 10 \text{ mg/m}^3$$

$$\text{chl } \underline{a} = 0.08\ (10)^{1.5} = 2.5 \text{ mg/m}^3$$

Dry algal biomass = 2.5x33 = 83 mg/m^3

Note that these low levels of chlorophyll a almost certainly mean that the lake is oligotrophic to mesotrophic, and that the Vollenweider method suggests worse conditions than may actually exist in this case.

Consequently, one might choose to use the Lorenzen model to evaluate K_1 and K_3 and determine whether the impoundment is at steady state with respect to phosphorus levels in the water column and sediment. Generally, this is the case where K_1K_3 lies in the range of 20 to 40. If K_1K_3 is outside of this range, field data should be obtained for current water column phosphorus.

Sediment volume, V_s	Irrelevant for steady-state solution
Phosphorus (water column)	.15 mg/l

$$K_3 = 0.5$$

$$K_1 = \frac{M - QC_w}{K_3 C_w A}$$

$$C_w = 0.15 \text{ mg/l} = .015 \text{ g/m}^3$$

$$K_1 = \left(\frac{1.24\text{x}10^7 \text{gP}}{\text{yr}} - \frac{9.13\text{x}10^7 \text{m}^3}{\text{yr}} \text{ x } \frac{.015\text{g}}{\text{m}^3}\right) \Big/ \left(.5 \text{ x } \frac{.015\text{g}}{\text{m}^3} \text{ x } 5.2 \text{ x } 10^7 \text{m}^2\right) = 28.3 \frac{\text{m}}{\text{yr}}$$

$$K_1K_3 = 44 \text{ x } 0.5 = 14$$

This result, therefore, gives reason to suspect non steady-state conditions for water column phosphorus. If more definitive answers are needed, additional field data should be collected.

END OF EXAMPLE V-14

5.5 IMPOUNDMENT DISSOLVED OXYGEN

Organic substances introduced into an impoundment with inflowing water, falling onto its surface, or generated in the water column itself through photosynthesis, may be oxidized by indigenous biota. The process consumes oxygen which may, in turn, be replenished through surface reaeration, photosynthetic activity, or dissolved oxygen in inflowing water. The dynamic balance between DO consumption and replenishment determines the net DO concentration at any point in time and at any location within the water column.

These processes result in characteristic dissolved oxygen (DO) concentrations in the water columns of stratified lakes and reservoirs (Figure V-28). During stratification, typically during summer months, the DO is highest on the surface due to photosynthesis and reaeration. It decreases through the thermocline and then, in the hypolimnion, the DO decreases to zero in those lakes that have high organic matter concentrations.

During spring, after turnover, when lakes are not stratified, the DO is essentially uniform. However, in highly organic lakes benthic processes can already begin to deplete oxygen from lower depths, as shown in Figure V-28.

Essentially, the patterns result from processes that are restricted due to incomplete mixing. The overall effects of such patterns as shown in Figure V-28, are to restrict fishery habitat and create water quality problems for downstream users, especially for deep water discharge.

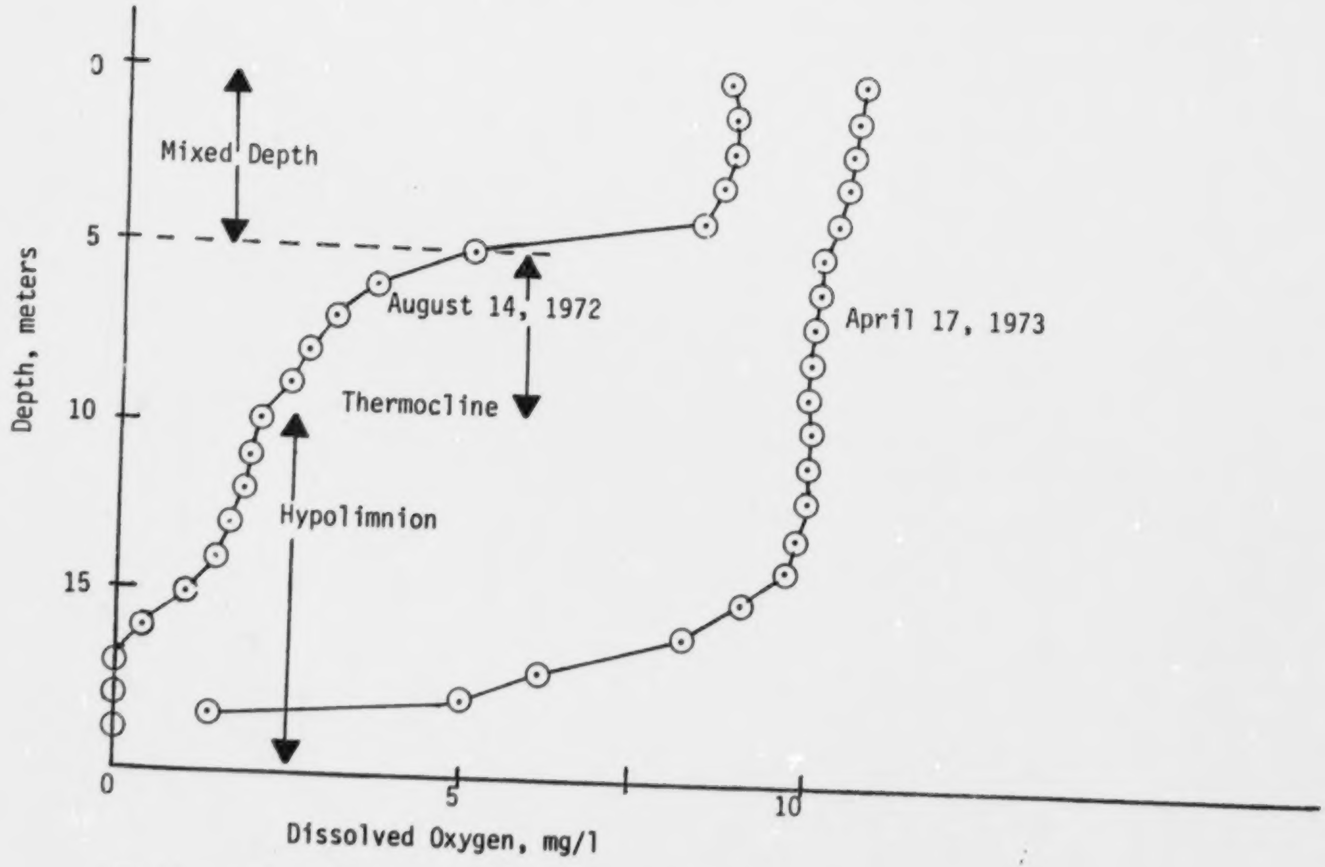


Figure V-28 Typical Patterns of Dissolved Oxygen (DO) in Hyrum Reservoir (Drury, et al., 1975)

BOD exertion is not the only sink for DO. Some important sources and sinks of impoundment dissolved oxygen are listed below:

SOURCES AND SINKS OF
IMPOUNDMENT DISSOLVED OXYGEN

Sources	Sinks
Photosynthesis Atmospheric reaeration Inflowing water Rainwater	Water Column BOD Benthic BOD Chemical oxidation Deoxygenation at surface Plant and animal respiration

Many of the processes listed above have a complex nature. For example, the atmospheric reaeration rate is dependent in part upon the near-surface velocity gradient over depth. The gradient, in turn, is influenced by the magnitude, direction, and duration of wind, as well as the depth and geometry of the impoundment.

Photosynthetic rates are affected by climatological conditions, types of cells photosynthesizing, temperature, and a number of biochemical and biological factors. Exertion of BOD is dependent upon the kind of substrate, temperature, dissolved oxygen concentration, presence of toxicants, and dosing rate.

Despite this degree of complexity, a number of excellent models of varying degrees of sophistication have been developed which include simulation of impoundment dissolved oxygen.

5.5.1 Simulating Impoundment Dissolved Oxygen

Because an unstratified impoundment generally may be considered as a slow-moving stream reach, only stratified impoundments are of interest here. For estimating DO in unstratified impoundments, one should refer to the methods described in Chapter 4.

To understand the phenomena affecting dissolved oxygen in a stratified impoundment and to gain an appreciation of both the utility and limitations of the approach presented later, it is useful to briefly examine a typical dissolved oxygen model. Figure V-29 shows a geometric representation of a stratified impoundment. As indicated in the diagram, the model segments the impoundment into horizontal layers. Each horizontal layer is considered fully mixed at any point in time, and the model advects and diffuses mass vertically into and out of each layer. The constituents and interrelationships modeled are shown schematically in Figure V-30.

The phenomena usually taken into account in an impoundment DO model include:

- Vertical advection
- Vertical diffusion
- Correction for element volume change
- Surface replenishment (reaeration)
- BOD exertion utilizing oxygen
- Oxidation of ammonia
- Oxidation of nitrite
- Oxidation of detritus
- Zooplankton respiration
- Algal growth (photosynthesis) and respiration
- DO contribution from inflowing water
- DO removal due to withdrawals

Many of the processes are complex and calculations in detailed models involve simultaneous solution of many cumbersome equations.

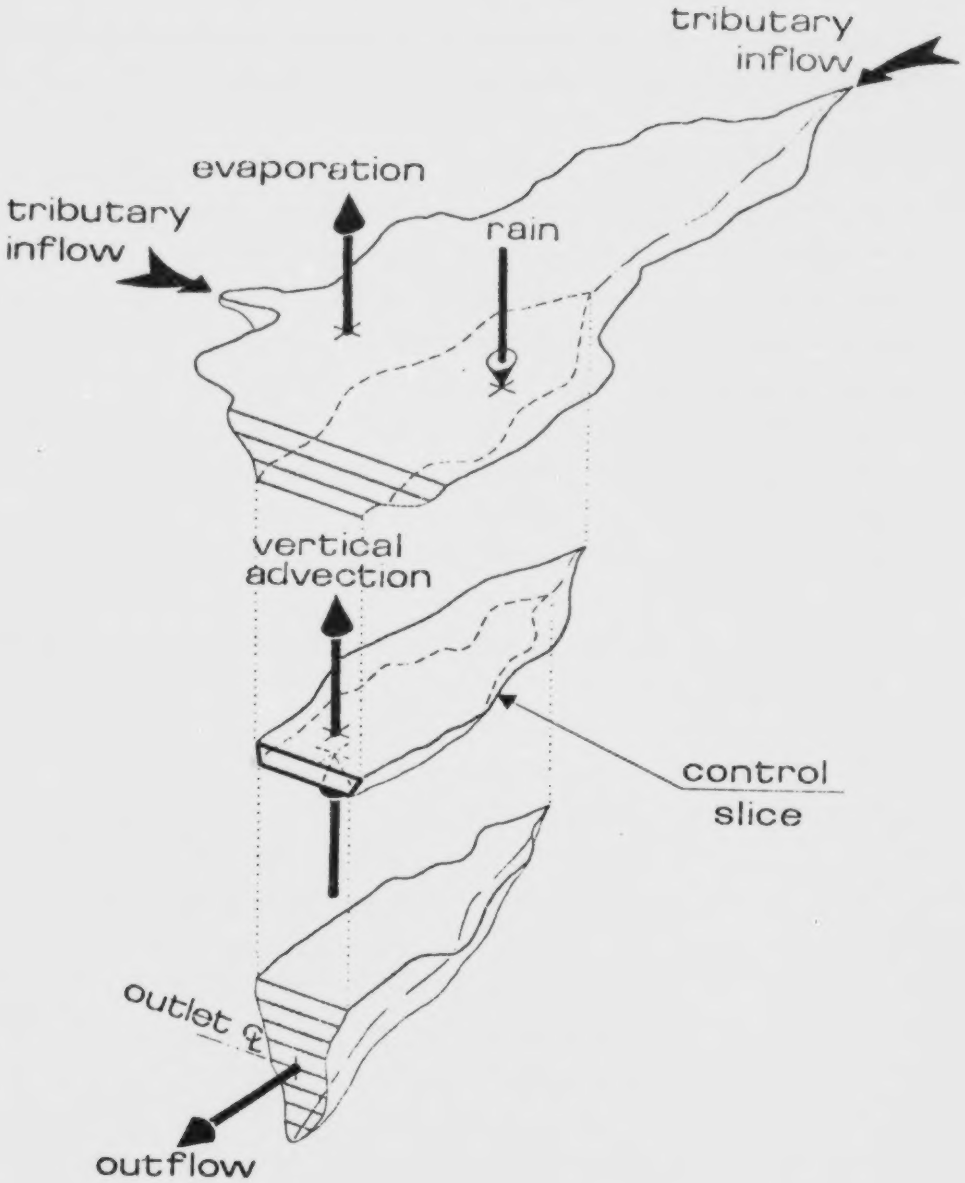


FIGURE V-29 GEOMETRIC REPRESENTATION OF A STRATIFIED IMPOUNDMENT (FROM HEC, 1974)

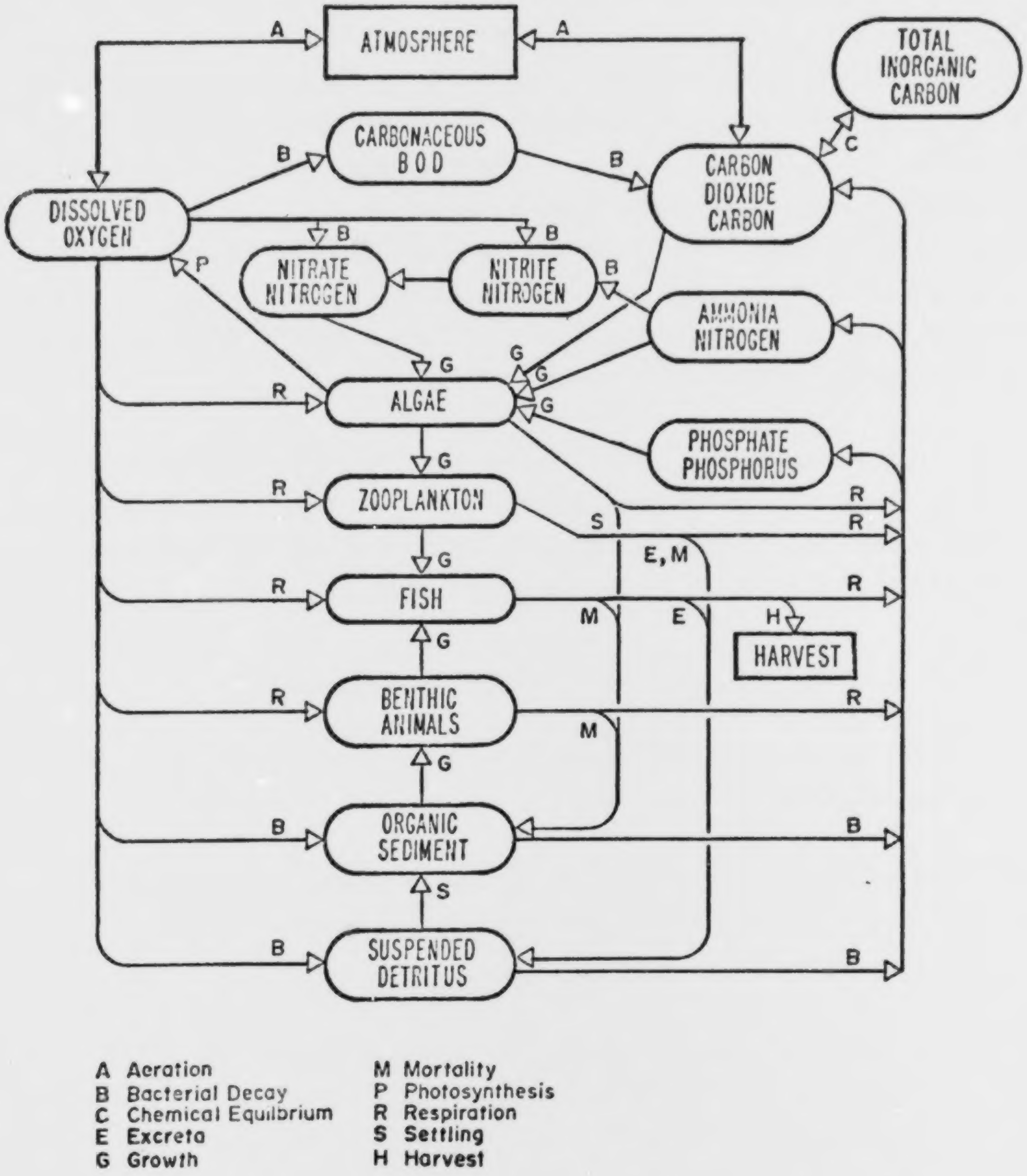


Figure V-30 Quality and Ecologic Relationships (From Hec, 1974)

Among the processes simulated are zooplankton-phytoplankton interactions, the nitrogen cycle, and advection-diffusion. Thus it is clear that a model which is comprehensive and potentially capable of simulating DO in impoundments with good accuracy is not appropriate for hand calculations. A large amount of data (coefficients, concentrations) are needed to apply such a model, and solution is most easily done by computer. Furthermore, some of the terms in the model equation of state do not improve prediction under some circumstances. This is true, for example, where there are no withdrawals or in an oligotrophic impoundment where chlorophyll _a_ concentrations are very low.

Hand calculations must be based upon a greatly simplified model to be practical. Since some DO-determining phenomena are more important than others and if some assumptions are made about the impoundment itself, it is feasible to develop such a model.

5.5.2 A Simplified Impoundment Dissolved Oxygen Model

For purposes of developing a model for hand calculations, the following assumptions are made:

- The only condition where DO levels may become dangerously low is in an impoundment hypolimnion and during warm weather.

- Prior to stratification, the impoundment is mixed. After strata form, the epilimnion and hypolimnion are each fully mixed.

- Dissolved oxygen in the hypolimnion is depleted essentially through BOD exertion. Significant BOD sources and sinks to the water column prior to stratification are algal mortality, BOD settling, and outflows. A minor source is influent BOD. Following formation of strata, sources and sinks of BOD are BOD settling out onto the bottom, water column BOD at the time of stratification, and benthic BOD.

- Photosynthesis is unimportant in the hypolimnion as a source of DO.
- Once stratification occurs (a thermocline gradient of 1°C or greater per meter of depth) no mixing of thermocline and hypolimnion waters occurs.
- BOD loading to the unstratified impoundment and to the hypolimnion are in steady-state for the computation period.

5.5.2.1 Estimating a Steady-State BOD Load to the Impoundment

Equation V-25 is an expression to describe the rate of change of BOD concentration as a function of time:

$$\frac{dC}{dt} = k_a - k_s C - k_1 C - \frac{QC}{V} \qquad \text{(V-25)}$$

where

C = the concentration of BOD in the water column in $\mathrm{mgl^{-1}}$

k_a = the mean rate of BOD loading from all sources in $\mathrm{mgl^{-1}\ day^{-1}}$

k_s = the mean rate of BOD settling out onto the impoundment bottom in $\mathrm{day^{-1}}$

k_1 = the mean rate of decay of water column BOD in $\mathrm{day^{-1}}$

Q = mean export flow rate in liters $\mathrm{day^{-1}}$

V = impoundment volume in liters

Integrating Equation V-25 gives:

$$C_t = \frac{(k_a + k_b C_o)e^{(k_b t)} - k_a}{k_b} \qquad \text{(V-26)}$$

where

C_t = concentration of BOD at time t
C_o = initial concentration of BOD
$k_b = -k_s - k_1 - \frac{Q}{V}$

To estimate the steady-state loading of BOD, we set dc/dt = 0 and obtain

$$C_{ss} = -\frac{k_a}{k_b} \qquad \text{(V-27)}$$

where

C_{ss} = steady-state water column BOD

Thus Equation (V-27) may be used to estimate a steady-state water column BOD concentration and Equation (V-26) may be used to compute BOD as a function of time, initial concentration of BOD, and the various rates.

5.5.2.2 Rates of Carbonaceous and Nitrogenous Demands

The rate of exertion of BOD and therefore the value of k_1 is dependent upon a number of physical, chemical, and biological factors. Among these are temperature, numbers and kinds of microorganisms, dissolved oxygen concentration, and the kind of organic substance involved. Nearly all of the biochemical oxygen demand in impoundments is related to decaying plant and animal matter. All such material consists essentially of carbohydrates, fats, and proteins along with a vast number of minor constituents. Some of these are rapidly utilized by bacteria, for example, the simple sugars, while some, such as the celluloses, are metabolized slowly.

Much of the decaying matter in impoundments is carbonaceous.

Carbohydrates (celluloses, sugars, starches) and fats are essentially devoid of nitrogen. Proteins, on the other hand, are high in nitrogen (weight of carbon/weight of nitrogen ≈ 6) and proteins therefore represent both carbonaceous and nitrogenous demands.

The rate of exertion of carbonaceous and nitrogenous demands differ. Figure V-31, which shows the difference graphically and as a function of time and temperature, may be considered to represent the system response to a slug dose of mixed carbonaceous and nitrogenous demands. In each two-section curve, especially where concentrated carbonaceous wastes are present, the carbonaceous demand is exerted first, and this represents the first stage of deoxygenation. Then nitrifiers increase in numbers and ammonia is oxidized through nitrite and ultimately to nitrate. This later phase is called the second phase of deoxygenation.

BOD decay (either nitrogenous or carbonaceous alone) may be represented by first order kinetics. That is, the rate of oxidation is directly proportional to the amount of material remaining at time t.

$$\frac{dC}{dt} = -kC \qquad \text{(V-28)}$$

The rate constant, k, is a function of temperature, bacterial types and numbers, composition and structure of the substrate, presence of nutrients and toxicants, and a number of other factors. The value of the first stage constant k_1 was first determined by Phelps in 1909 for sewage filter samples. The value was 0.1 (Camp, 1968). More recent data show that at 20°C, the value can range from 0.01 for slowly metabolized industrial waste organics to 0.3 for relatively fresh sewage (Camp, 1968).

The typical effect of temperature on organic reactions is to double reaction rates for each temperature rise of 15^{o}C. The relationship for correcting k_1 for temperature is:

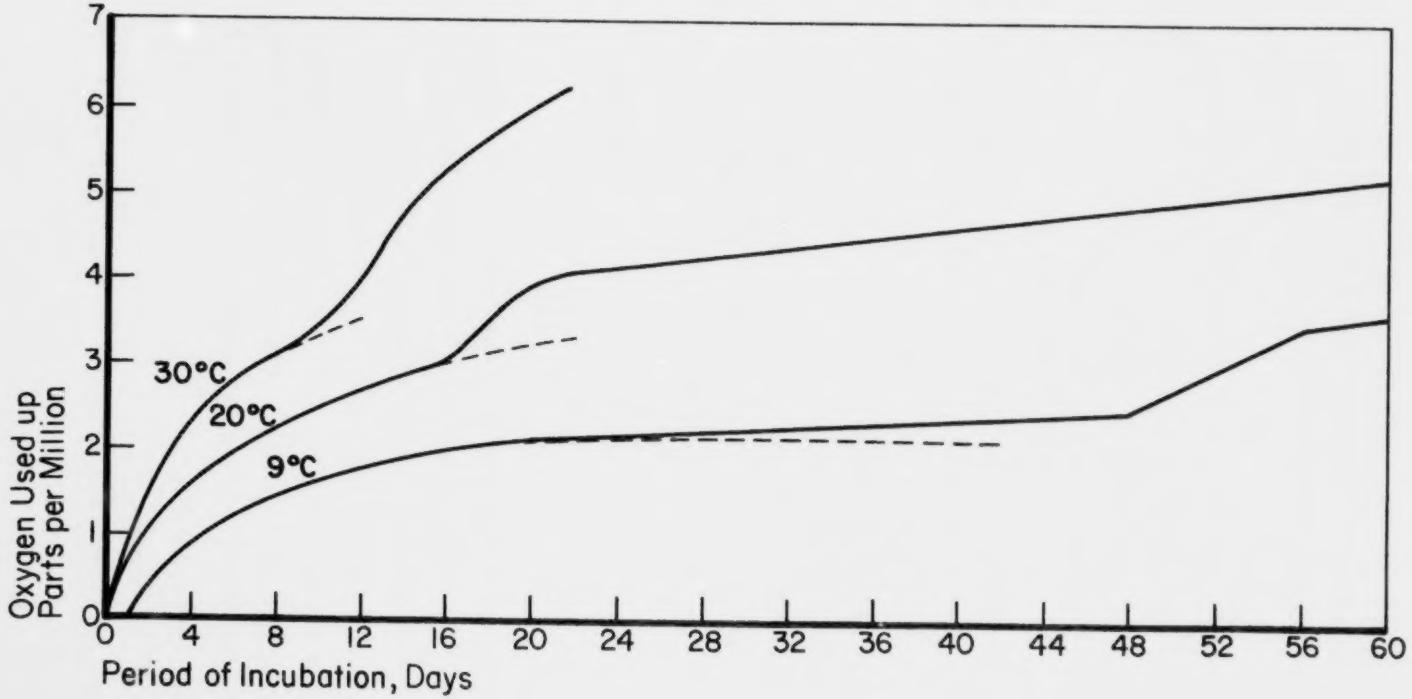


FIGURE V-31 RATE OF BOD EXERTION AT DIFFERENT TEMPERATURES SHOWING THE FIRST AND SECOND DEOXYGENATION STAGES

$$k_{1,(T)} = k_{1,(20°C)}\ \theta^{(T-20)} \qquad \text{(V-29)}$$

where

T = the temperature of reaction

θ = correction constant = 1.047

However, Thereault has used a value for θ of 1.02, while Moore calculated values of 1.045 and 1.065 for two sewages and 1.025 for river water (Camp, 1968).

Streeter has determined the rate of the nitrification or second deoxygenation stage in polluted streams. At 20°C, k_1 for nitrification is about 0.03 (Camp, 1968). Mobre found the value to be .06 at 20°C and .035 at 10°C (Camp, 1968). For purposes of this analysis, BOD exertion will be characterized as simple first order decay using a single rate constant.

Benthic demand, which is important in later computations, may vary over a wide range because in addition to the variability due to the chemical nature of the benthic matter, rates of oxidation are limited by upward diffusion rates of oxidizable substances through pores in the benthos. Since the nature of the sediment is highly variable, benthic oxygen demand rates vary more than values for k_1 in the water column. In a study using sludges through which oxygenated water was passed, initial rates of demand ranged from 1.02 g/m^2 day (see Table V-10) for a sludge depth of 1.42 cm up to 4.65 g/m^2 day for a sludge depth of 10.2 cm (Camp, 1968). In that study, the values found were for initial demand since the sludge was not replenished. The rate per centimeter of sludge depth, then, can vary from a low of 0.46 g/m^2 day for 10.2 centimeter depth sludge up to 0.76 g/m^2day for 1.42 centimeter depth sludge.

TABLE V-10

OXYGEN DEMAND OF BOTTOM DEPOSITS
(AFTER CAMP, 1968)

Benthic Depth (mean) cm	Initial Volume of Solids, kgm^{-2}	Initial Area Demand		day^{-1}
		L (gm^{-2})	Initial Demand $gm^{-2}day^{-1}$	$k_4(20^oC)$
10.2	3.77	739	4.65	.0027
4.75	1.38	426	3.09	.0031
2.55	0.513	227	1.70	.0032
1.42	0.188	142	1.08	.0033
1.42	0.188	134	1.02	.0033

The constant loading rate (k_a) used in Equation (V-25) is best estimated from historical data. Alternatively, inflow loading (see Chapter IV) and algal productivity estimates (this chapter) may be used. In the latter case, a value must be adopted for the proportion of algal biomass ultimately exerted as BOD. To a first approximation, k_a may be estimated using this value and adopting some percentage of maximal primary productivity (see Figure V-25). Thus,

$$k_a(\text{algae}) = SMP \times 10^{-3}/D \qquad \text{(V-30)}$$

where

k_a(algae) = algal contribution to BOD loading rate

S = stoichiometric conversion from algal biomass as carbon to BOD = 2.67

M = Proportion of algal biomass expressed as an oxygen demand (unitless)

P = Primary production in $mgCm^{-2}day^{-1}$

The difference between algal biomass and the parameter M representing the proportion of algal biomass exerted as BOD may be conceptualized as accounting for such phenomena as incorporation of algal biomass into fish tissue which either leaves the impoundment or is harvested, loss of carbon to the atmosphere as CH_4, and loss due to outflows.

The settling rate coefficient, k_s in Equation (V-25) must be estimated for the individual case. It represents the rate at which dead plant and animal matter (detritus) settles out of the water column prior to oxidation. Clearly, this coefficient is sensitive to the composition and physical characteristics of suspended matter and the turbulence of the system. Quiescence and large particle sizes in the organic fraction will tend to give high values for k_s while turbulence and small organic fraction particle sizes will give small values for k_s.

5.5.2.3 Estimating a Pre-Stratification Steady-State Dissolved Oxygen Level

Prior to stratification, the impoundment is assumed to be fully mixed. One of the important factors leading to this condition is wind stress, which also serves to reaerate the water. As a rule, unless an impoundment acts as a receiving body for large amounts of nutrients and/or organic loading, dissolved oxygen levels are likely to be near saturation during this period (D.J. Smith, pers. comm., November, 1976). Table V-11 shows saturation dissolved oxygen levels for fresh water as a function of temperature, and DO levels may be estimated accordingly.

The hypolimnetic saturation dissolved oxygen concentration is determined by using the average (or median) temperature for the hypolimnion as determined during the period of interest throughout the depth of the hypolimnion. Information on the hypolimnion are obtained using the procedures described in Section 5.2. For example, hypolimnetic water at the onset of stratification might be 4-5°C and during the critical summer months be 10°C. The value 10°C should be used having a saturation DO of 11.3 mg/l.

TABLE V-11

SOLUBILITY OF OXYGEN IN WATER (STANDARD METHODS, 1971)

Temp. in ^{o}C	Chloride Concentration in Water - mg/l					Difference per 100 mg Chloride
	0	5,000	10,000	15,000	Sea Water	
	Dissolved Oxygen - mg/l					
0	14.6	13.8	13.0	12.1	11.3	0.017
1	14.2	13.4	12.6	11.8	11.0	0.016
2	13.8	13.1	12.3	11.5	10.8	0.015
3	13.5	12.7	12.0	11.2	10.5	0.015
4	13.1	12.4	11.7	11.0	10.3	0.014
5	12.8	12.1	11.4	10.7	10.0	0.014
6	12.5	11.8	11.1	10.5	9.8	0.014
7	12.2	11.5	10.9	10.2	9.6	0.013
8	11.9	11.2	10.6	10.0	9.4	0.013
9	11.6	11.0	10.4	9.8	9.2	0.012
10	11.3	10.7	10.1	9.6	9.0	0.012
11	11.1	10.5	9.9	9.4	8.8	0.011
12	10.8	10.3	9.7	9.2	8.6	0.011
13	10.6	10.1	9.5	9.0	8.5	0.011
14	10.4	9.9	9.3	8.8	8.3	0.010
15	10.2	9.7	9.1	8.6	8.1	0.010
16	10.0	9.5	9.0	8.5	8.0	0.010
17	9.7	9.3	8.8	8.3	7.8	0.010
18	9.5	9.1	8.6	8.2	7.7	0.009
19	9.4	8.9	8.5	8.0	7.6	0.009
20	9.2	8.7	8.3	7.9	7.4	0.009
21	9.0	8.6	8.1	7.7	7.3	0.009
22	8.8	8.4	8.0	7.6	7.1	0.008
23	8.7	8.3	7.9	7.4	7.0	0.008
24	8.5	8.1	7.7	7.3	6.9	0.008
25	8.4	8.0	7.6	7.2	6.7	0.008
26	8.2	7.8	7.4	7.0	6.6	0.008
27	8.1	7.7	7.3	6.9	6.5	0.008
28	7.9	7.5	7.1	6.8	6.4	0.008
29	7.8	7.4	7.0	6.6	6.3	0.008
30	7.6	7.3	6.9	6.5	6.1	0.008
31	7.5					
32	7.4					
33	7.3					
34	7.2					
35	7.1					

Most lakes are near sea level (<2000 ft elevation) and are relatively fresh (<2000 mg TDS/l). For lakes that do not meet these criteria, corrections for atmospheric pressure differences and salting out due to salinity might be needed. Pressure effects can be approximated by using a ratio of barometric pressure (B) for the elevation of interest and sea level (BSTP) as follows:

e.g. B at 4600 ft elevation,

$$\frac{B}{BSTP} = \frac{640}{760}\text{, in mm Hg,} = 0.84$$

$$\text{DOsat at } 10^{\circ}\text{C} = 0.84 \times 11.3 = 9.5 \text{ mg/l.}$$

Chloride is an estimator of dilutions of sea water in fresh water where 20000 mg Chloride/l is equivalent to 35000 mg salt (TDS/l, that is, typical ocean water.

5.5.2.4 Estimating Hypolimnion DO Levels

The final step in use of this model is preparation of a DO-versus-time plot for the hypolimnion (or at least estimation of DO at incipient overturn) and estimation of BOD and phosphorus loadings which result in acceptable hypolimnion DO levels. An equation to compute DO at any point in time during the period of stratification is

$$\frac{dO}{dt} = -k_1C - k_4L/D \qquad \text{(V-31)}$$

where

O = dissolved oxygen in ppm

k_4 = benthic decay rate in day^{-1}

L = areal BOD load in gm^{-2}

D = depth in m

The second term in the equation requires that an estimate be made of the magnitude of BOD loading in benthic deposits. To do this within the present framework, it is assumed that BOD settles out ...

throughout the period of stratification. Although many different assumptions have been made concerning benthic BOD decay, it was assumed that benthic demand was a function of BOD settling and the rate of benthic BOD decay. This BOD includes that generated in the system by algal growth and that which enters in tributaries and waste discharges. Based upon the rate of settling used earlier in estimating a steady-state BOD concentration (Equation (V-25)) and rate of decay for conditions prior to stratification, the rate of benthic matter accumulation is:

$$\frac{dL}{dt} = k_s C_{ss} D - k_4 L \qquad \text{(V-32)}$$

where

C_{ss} = concentration of BOD in the water column in gm^{-3} at steady-state

The assumption of steady-state BOD concentration reduces Equation (V-32) to the same form as Equation (V-25) and integration gives:

$$L_t = \frac{(k_s D C_{ss} - k_4 L_0) e^{-k_4 t} - k_s D C_{ss}}{-k_4} \qquad \text{(V-33)}$$

For steady-state deposition ($dL/dt = 0$, $Dk_s C_{ss}$ = constant),

$$L_{ss} = \frac{k_s C_{ss} D}{k_4} \qquad \text{(V-34)}$$

where

L_{ss} = steady-state benthic BOD load in gm^{-2}

Application of Equation (V-34) with k_s and k_4 appropriately chosen for the month or two preceding stratification will give an estimate of the benthic BOD load upon stratification. Application of Equation (V-33) gives the response of L to different water column BOD (steady-state) loading rates and changes in rate coefficients.

After strata form, benthic matter decays while hypolimnion water column BOD decays and settles. The change in L over the period of stratification is

$$\frac{dL}{dt} = -k_4L + Dk_sC \qquad \text{(V-35)}$$

Since

$$\frac{dC}{dt} = -k_sC - k_1C = -(k_1+k_s)C \qquad \text{(V-36)}$$

and

$$C_t = C_o\, e^{-(k_1 + k_s)t} \qquad \text{(V-37)}$$

$$\frac{dL}{dt} = -k_4L + Dk_sC_o\, e^{-(k_1 + k_s)t} \qquad \text{(V-38)}$$

Then

$$L_t = \left(L_o + \frac{Dk_sC_o}{k_s+k_1-k_4}\right)e^{-k_4t} - \left(\frac{Dk_sC_o}{k_s+k_1-k_4}\right)e^{(-k_s-k_1)t} \qquad \text{(V-39)}$$

Water column BOD in the hypolimnion is given by Equation (V-36) and the integrated form is Equation (V-37).

Note that k_s, the settling coefficient is equal to v_s/D where v_s is the settling velocity of the BOD, and D is the depth of the hypolimnion (or when the impoundment is unstratified, D is the depth of the entire impoundment). Also note that we usually assume that the DO is at saturation at the onset of stratification. Thus we can ignore the assumptions and calculations (Equation V-32 to V-34) done for periods prior to onset.

The equation presented earlier (Equation V-31) for hypolimnion DO was:

$$\frac{dO}{dt} = -k_1C - k_4L/D$$

Equation (V-31) is not integrable in its present form, but since L and C are defined as functions of t (Equations (V-39) and (V-37) respectively), it is possible to determine dissolved oxygen in the water column. The equation for oxygen at time t is:

$$O_t = O_o - \Delta O_L - \Delta O_c \qquad \text{(V-40)}$$

where

O_t = dissolved oxygen at time t
O_o = dissolved oxygen at time t = 0
ΔO_L = dissolved oxygen decrease due to benthic demand
ΔO_c = dissolved oxygen decrease due to hypolimnion BOD

From Equation (V-39), and using L_{ss} as L_o and C_{ss} as C_o,

$$\Delta O_L = \left(\frac{L_{ss}}{D} + \frac{k_sC_{ss}}{k_s+k_1-k_4}\right)\left(1-e^{-k_4t}\right) - \left(\frac{k_sC_{ss}}{k_s+k_1-k_4}\right)\left(\frac{k_4}{k_s+k_1}\right)\left(1-e^{-(k_s+k_1)t}\right) \qquad \text{(V-41)}$$

and from Equation (V-37),

$$\Delta O_c = \frac{k_1C_{ss}}{k_1+k_s}\left(1-e^{-(k_1+k_s)t}\right) \qquad \text{(V-42)}$$

Solution of Equation (V-40) gives an estimated DO concentration in the hypolimnion as a function of time.

To compute equation (V-40), a simpler form of equation (V-41) can be derived by substituting as follows:

since $L_{ss} = \frac{k_{ss}C_{ss}D}{k_4}$,

$$\Delta O_L = \left(\frac{k_s C_{ss}}{k_s+k_1-k_4}\right)\left(\frac{k_s+k_1}{k_4}\right)\left(1-e^{-k_4 t}\right) - \left(\frac{k_4}{k_s+k_1}\right)\left(1-e^{-(k_s+k_1)t}\right) \qquad \text{(V-43)}$$

To simplify computations, the following stepwise solutions can be made:

$$A = \frac{k_s\ C_{ss}}{k_s+k_1-k_4}$$

$$B = \frac{k_s+k_1}{k_4}$$

$$C = 1-e^{-k_4 t}$$

$$E = 1-e^{-(k_s+k_1)t}$$

$$F = \frac{k_1\ C_{ss}}{k_1+k_s}$$

Then,

$$\Delta O_L = A\left(B \cdot C - \frac{E}{B}\right)$$

$$\Delta O_C = E \cdot F$$

5.5.3 Temperature Corrections

All reactions are computed on the basis of the optimum temperature, but the environment is often at different temperatures. Some rate coefficients for chemical and biological reactions vary with temperature. A simple correction for such rate coefficients to 20°C is as follows:

$$K_T = K_{T20} \times 1.047^{(T - 20^oC)}$$

For example, if a rate at 20 C = 0.01 and the lake is at 10°C, then

$$K_T = 0.01 \times 1.047^{(10 - 20)}$$

$$K_T = 0.00632$$

Generally the following optima are used:

- k_1 - first order decay rate for water column BOD, use 20°C.
- k_4 - benthic BOD decay, use 20°C.
- P - productivity rate, use 30° C.

In the screening methods we do not have to correct for temperature except in the oxygen calculation for the rate coefficients, K_1, K_4, P and in the toxics section (5.6) for the biodegradation rate coefficients.

EXAMPLE V-15

Quiet Lake
(Comprehensive Example)

Quiet Lake is located a few miles south of Colton, New York. The lake is roughly circular in plan view (Figure V-32) and receives inflows from three tributaries. There is one natural outlet from the lake and one withdrawal used for quarrying purposes.

The first step in evaluation of lake hypolimnion DO levels is physical and water quality data collection. Table V-12 shows characteristics of Quiet Lake, Table V-13 shows tributary discharge data along with withdrawal and outflow levels, and Table V-14 provides precipitation and runoff information.

In order to evaluate hypolimnion DO as a function of time, the very first question to be answered is, does the impoundment stratify? If so, what are the beginning and ending dates of the stratified period, how deep is the upper surface of the hypolimnion, and what is its volume, and what is the distribution of hypolimnion mean temperatures during the period? To answer these questions, either use field observation data, or apply some computation technique such as that presented earlier in this section. Assuming that methods presented earlier are used, the selection of appropriate thermal profile curves hinges around three factors. These are

- Climate and location
- Hydraulic residence time, and
- Impoundment geometry

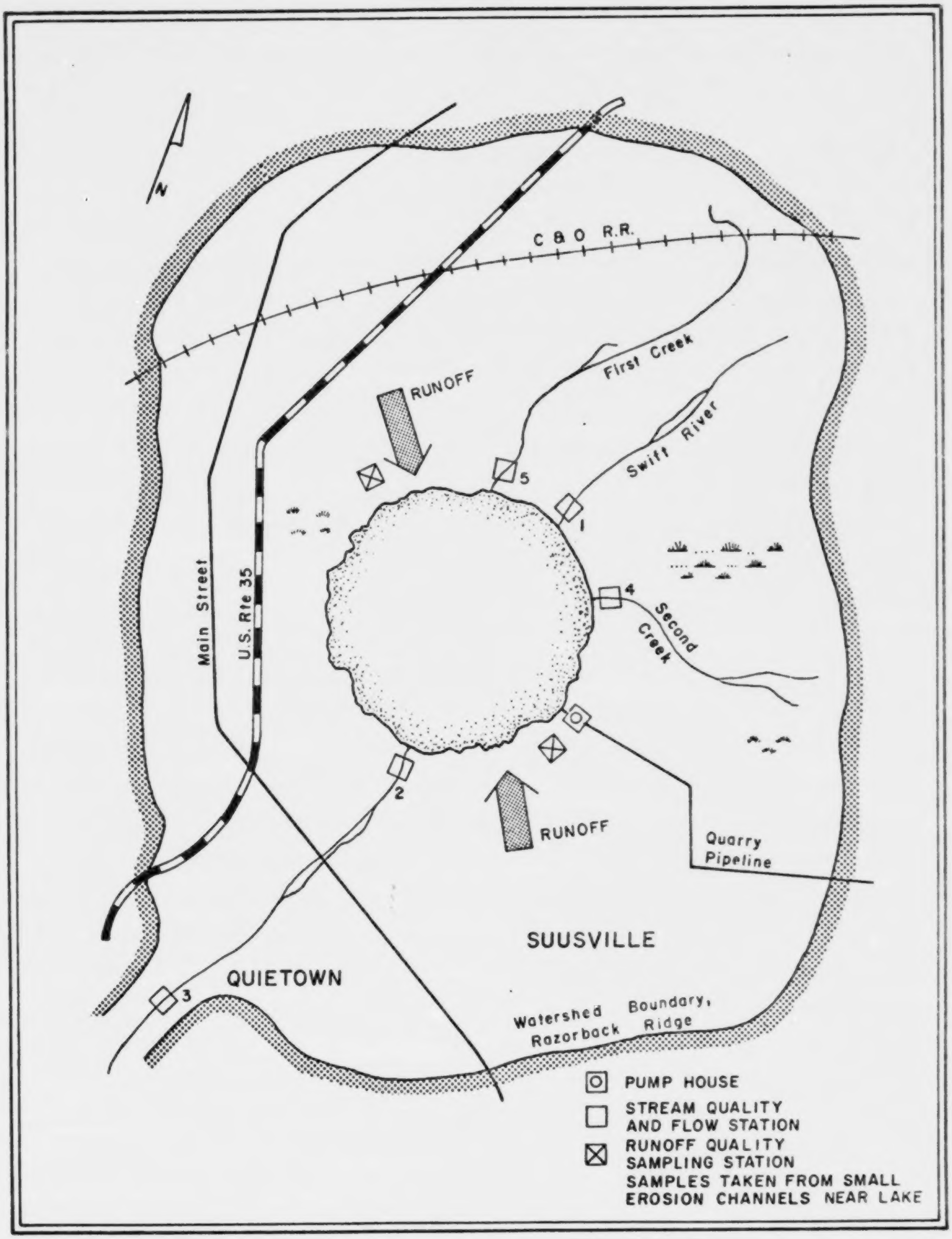

N
C & O R.R.
First Creek
RUNOFF
Swift River
5
1
4
Second Creek
Main Street
U.S. Rte 35
2
RUNOFF
Quarry Pipeline
SUUSVILLE
QUIETOWN
3
Watershed Boundary, Razorback Ridge
PUMP HOUSE
STREAM QUALITY AND FLOW STATION
RUNOFF QUALITY SAMPLING STATION
SAMPLES TAKEN FROM SMALL EROSION CHANNELS NEAR LAKE

FIGURE V-32 QUIET LAKE AND ENVIRONS

TABLE V-12

CHARACTERISTICS OF QUIET LAKE

Quiet Lake	
Length (in direction of flow)	3.5 miles = 18,480 ft.
Width	4.0 miles = 21,120 ft.
Mean Depth	22 ft.
Maximum Depth	27 ft.
Water Column P	$0.014 \leq P \leq .032$

TABLE V-13

WATER QUALITY AND FLOW DATA FOR TRIBUTARIES TO QUIET LAKE. DATA REPRESENT MEAN FIGURES FOR 1970-1975.

Swift River (Station 1, above Quiet Lake)

Month	Mean Flow, cfs	Total N	Total P ppm	BOD
October	54	2.2	0.2	3
November	38	4.1	0.08	4
December	10	5.3	0.10	6
January	5	6.1	0.20	12
February	2	5.0	0.15	10
March	8	4.3	0.08	12
April	40	3.3	0.04	10
May	55	2.1	0.02	8
June	85	2.8	0.02	4
July	150	2.9	0.02	2
August	70	1.0	0.02	1
September	85	2.4	0.03	1

TABLE V-13 (Continued)

First Creek (Station 5)

Month	Mean Flow, cfs	Total N	Total P ppm	BOD
October	5	1.0	.01	0.5
November	3	2.0	.01	1.0
December	2	0.5	.02	1.5
January	2	1.2	.01	1.0
February	3	1.3	.02	0.8
March	4	2.3	.01	0.6
April	6	2.0	.01	0.5
May	8	1.8	.02	0.6
June	10	1.6	.01	0.8
July	8	1.4	.01	0.8
August	6	1.5	.00	1.0
September	4	0.8	.00	1.2

Second Creek (Station 4)

Month	Mean Flow, cfs	Total N	Total P ppm	BOD
October	14.0	15	.15	7
November	13.0	16	.08	8
December	12.5	10	.20	10
January	5.0	9	.15	7
February	1.2	12	.12	7
March	2.0	13	.10	6
April	2.5	8	.11	7
May	4.0	6	.07	9
June	8.0	5	.08	12
July	12.0	7	.20	3
August	8.0	6	.22	4
September	5.5	8	.25	8

TABLE V-13 (Continued)

Swift River (Stations 2 and 3) and Pumped Withdrawal

Month	Pumped Withdrawal, cfs	Mean Monthly Flow, cfs	
		Station 2	Station 3
October	22.6	69.5	77.0
November	22.0	50.0	55.0
December	3.5	20.0	22.0
January	1.2	7.5	9.0
February	0.8	1.2	1.4
March	0.4	9.1	10.1
April	12.0	44.5	48.75
May	24.0	63.2	69.5
June	30.7	100.0	110.0
July	89.5	168.5	184.8
August	29.8	80.6	88.5
September	43.9	91.3	100.25

Notes: All three tributaries have their headwaters within the shed. The net inflow-outflow to the groundwater is known to be close to zero in the two creeks. Swift River is usually about 10% effluent over its entire length (10% of flow comes into the river from the groundwater table).

TABLE V-14

PRECIPITATION AND RUNOFF DATA FOR QUIET LAKE WATERSHED. VALUES ARE MEANS OF DATA COLLECTED FROM BOTH STATIONS (SEE FIGURE V-31). THE WATERSHED HAS AN AREA OF 55 SQUARE MILES INCLUDING THAT OF THE LAKE

Month	Mean Total Monthly Precipitation, inches	Runoff Quality Total N	Total P ppm	BOD
October	3.0	6.0	0.1	27
November	2.4	6.5	0.2	37
December	1.0	4.0	0.1	46
January	0.5	3.0	0.008	34
February	0.3	1.0	0.07	33
March	0.6	1.5	0.1	30
April	2.0	2.5	0.15	40
May	2.8	3.2	0.25	50
June	4.2	3.6	0.20	40
July	7.6	7.0	0.40	37
August	3.5	7.8	0.60	45
September	4.2	9.2	0.80	50
Total	32.1			

Note: Infiltration to the water table on a monthly basis accounts for roughly 30% of precipitation volume.

In terms of climate and location, the Quiet Lake area is similar to Burlington, Vermont. Examination of the Burlington plots from Appendix D reveals that a 20-foot maximum depth impoundment can stratify in an area shielded from the wind. The area surrounding Quiet Lake does provide good shielding, so the next task is to estimate the hydraulic residence time to select a specific set of plots.

Inspection of all Burlington plots indicates that stratification is likely to occur at most from May to August. Accordingly, for purposes of plot selection, we are most interested in a mean hydraulic residence time based on flows in the period from about March to August. Since hydraulic residence time (τ_w) is given by $\tau_w = V/Q$, we compute mean Q ($\bar{Q}$). $\bar{Q}$ represents the average of tributary inflows during this period, computed as follows:

$$\bar{Q} = \underset{\text{(Swift River)}}{\frac{8+40+55+85+150+70}{6}} + \underset{\text{(First Creek)}}{\frac{4+6+8+10+8+6}{6}} + \underset{\text{(Second Creek)}}{\frac{2+2.5+4+8+12+8}{6}}$$

$$\bar{Q} = 68+7+6.08 = 81.1 \text{ cfs}$$

However, in order to fully account for mass transport as well as properly estimate hydraulic residence time, one more factor should be considered. This is non-point inflow. At this point, we have enough information to estimate the stormwater contribution directly to Quiet Lake. In view of the available data, the computation is as follows:

$$Q_s = APK(1-L) - \left(\sum_{i=1}^{n} Q_i(1-I_i)\right)$$

where

Q_s = stormwater or non-point inflow in cfs (excluding rivers and creeks)

A = area of shed in square miles

n = number of tributaries

Q_i = monthly mean pickup (in cfs) in the ith tributary

P = monthly total precipitation, in inches per month

I_i = percent (expressed as a decimal) of flow contributed by exfiltration (from the water table into the channel)

L = the proportion of precipitation lost by infiltration into the soil (expressed as a decimal)
K = unit correction = 0.895 $ft^3 mo\ mi^{-2} in^{-1} sec^{-1}$

As an example, the computation for October is:

$$Q_s = 55\ mi^2 \times 3.0\ \frac{in}{mo} \times 0.896\ \frac{ft^3 mo}{mi^2 in\ sec} \times (1-0.3) -$$

$$\left(54(1-0.1)+5(1-0.0)+14(1-0.0)+(77-69.5)(1-0.1)\right) \simeq 29.1\ cfs$$

Now, since we know the pumped withdrawal rates as well as the difference between flows at stations 2 and the sum of 1, 4, and 5, and that the impoundment surface is at steady-state over the mouth, we also can estimate the net infiltration rate from the lake into the groundwater. The infiltration rate is (again, for October):

$$\text{Net efflux} = Q_{(sta\ 1+4+5)} - Q_2 + Q_s - Q_w$$

$$= 73.0 - 69.5 + 29.1 - 22.6 = 10.0\ cfs$$

Note that the pickup in each channel above Quiet Lake is equal to the flow at the pertinent sampling station. This is the case because the three channels have their headwaters within the watershed. If one were concerned about a subshed with tributary headwaters above the subshed boundary, the difference in Q between each of stations 1, 4, and 5 and the respective flows at the upstream subshed boundary would be used.

To estimate hydraulic residence time add the mean stormwater contribution over the months of interest to that of the tributaries, as computed earlier. The individual stormwater computations are not shown. The method is as just described.

$$\bar{Q}_{total} = 81.1 + \frac{6.6+20.7+29.4+41.4+92.5+36.6}{6} = 119\ cfs$$

Then the hydraulic residence time is given by:

$$\tau_w = V/Q \doteq \pi r^2 D/Q$$

$$r = \left[\frac{L+W}{4} \times 5280 \right]$$

where

L = length of the lake in mi.

W = width of the lake in mi.

D = mean depth in ft.

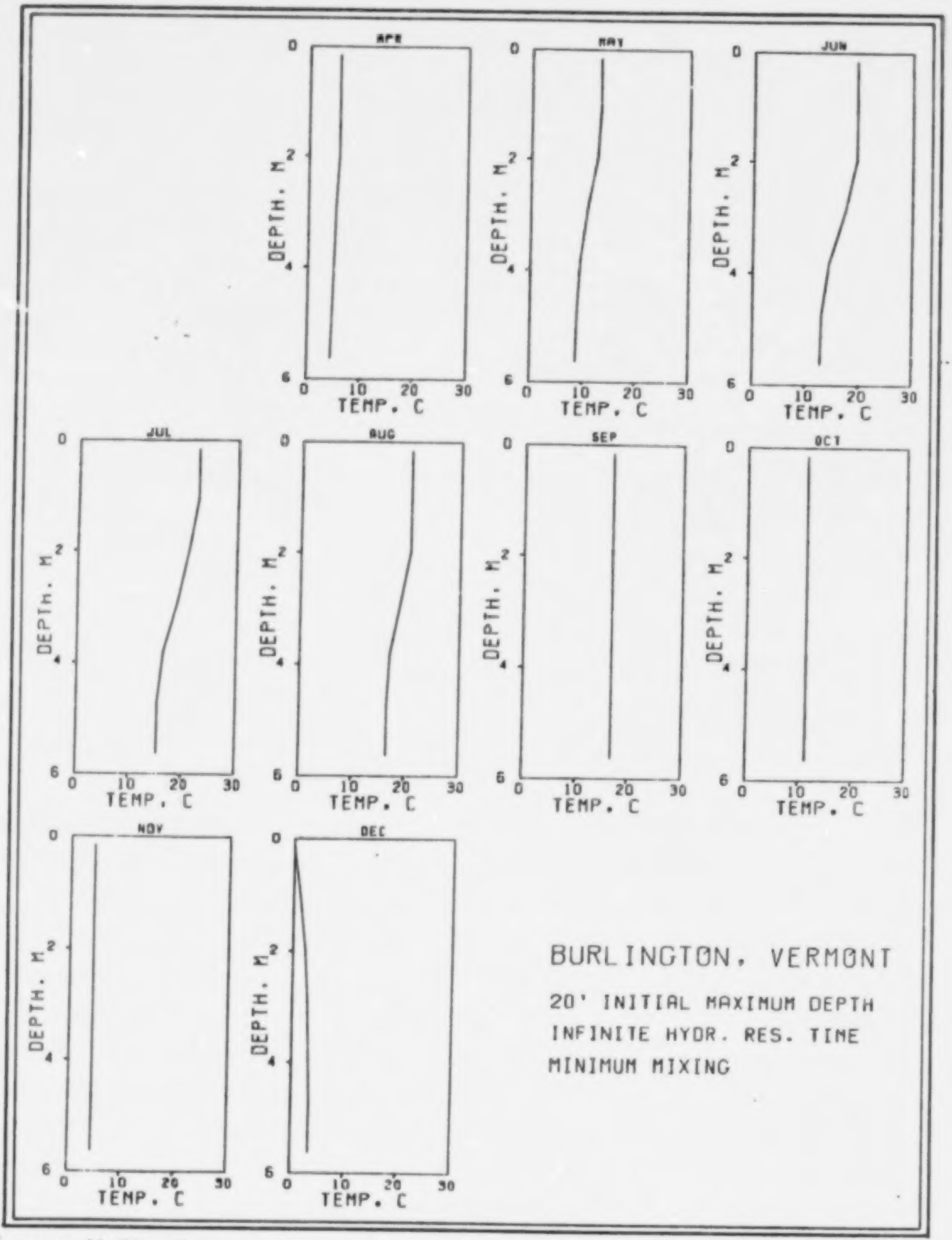
r = radius in ft.

$$\tau_w = 3.14 \times \left[\frac{3.5+4}{4} \times 5280 \right]^2 \times 22/119$$

$$= 5.69\text{x}10^7 \text{ sec} = 658 \text{ days}$$

Accordingly, the infinite hydraulic residence time plots for a 20-foot deep, wind-protected, Burlington, Vermont, impoundment should suffice. Note that the entire impoundment volume was used in the above computation. Strictly, one should use the epilimnion volume during stratification. In this case, such a change would not alter selection of the plots because τ_w would still be greater than 200 days. A reproduction of the appropriate plot from Appendix D is presented in Figure V-33. As indicated, Quiet Lake is likely to be weakly stratified from May to August inclusive, with a thermocline temperature gradient of about $1°\text{ft}^{-1}$. The hypolimnion should extend downward to the bottom from a depth of about 3-1/2 meters, giving a mean hypolimnion depth of

$$D_H = \frac{22 \text{ ft}}{3.28 \text{ ft m}^{-1}} - 3.5 \text{ m} = 3.2 \text{ meters}$$



BURLINGTON, VERMONT

20' INITIAL MAXIMUM DEPTH
INFINITE HYDR. RES. TIME
MINIMUM MIXING

FIGURE V-33 THERMAL PROFILE PLOTS FOR USE IN QUIET LAKE EXAMPLE

The approximate hypolimnion volume, then, is

$$V_H = \frac{D_H}{D_{Total}} \times V_{Total}$$

$$V_H = \frac{3.2m}{6.7m} \times 1.9 \times 10^{11} \ell = 9.2 \times 10^{10} \ell$$

Over the period of interest, the hypolimnion mean temperature distribution is:

Month	Mean Temperature, °C
March	2.0
April	5.5
May	9.5
June	12.5
July	14.0
August	15.5

The next step in use of the DO model is to determine a steady-state or mean water column BOD loading (k_a) and DO level prior to stratification. This is a multi-step process because of the several BOD sources. The sources are tributaries, runoff, and primary productivity. First, we estimate algal productivity using methods of this chapter (or better, field data).

Using the curve in Figure V-26 and phosphorus data from Table V-13, the maximal primary productivity should be in the range 1,400 mg $Cm^{-2}day^{-1}$ to 1,900 $mgCm^{-2}day^{-1}$. To convert to loading in $mgl^{-1}day^{-1}$, divide by ($1000\ lm^{-3} \times 6.7m$). This gives the loading as 0.21 to 0.28 $mgl^{-1}day^{-1}$.

Now assuming that maximal productivity occurs at about 30°C and that productivity rates obey the same temperature rule as BOD decay, temperature-adjusted estimates of productivity rates can be made. Using the maximal rate range of 0.21 to 0.28 $mgl^{-1}day^{-1}$, the adjusted rates are:

$$\begin{aligned}\text{Productivity} &= (0.21,\ 0.28) \times 1.047^{(3.75-30)}\\ &= (.06,.08)\ mgl^{-1}\ day^{-1}\end{aligned}$$

Then, according to Equation (V-30) and assuming $M = 1$, k_a due to algae is estimated by:

$$k_a(\text{algae}) = 2.67 \times (.06,\ .08) = (.16,\ .21)\ mgl^{-1}day^{-1}$$

The next contributor to water column BOD is BOD loading of inflowing waters. The value to be computed is the loading in milligrams per liter of impoundment water per day.

$$\text{Daily BOD loading rate} = \left(\sum_{i=1}^{n} \sum_{j=1}^{L_i} d_i Q_{i,j}\ C_{i,j} \right) \Big/ V\sum_{k=1}^{n} d_k$$

where n = the number of time periods of measurement
V = volume of impoundment in liters
d = the number of days per time period
L = the number of inflows

For all inflows, the value is therefore approximately:

$$k_{a(Trib)} = (\underset{\substack{\text{(Swift}\\\text{River)}}}{2185} + \underset{\substack{\text{(First}\\\text{Creek)}}}{48.3} + \underset{\substack{\text{(Second}\\\text{Creek)}}}{643.9} + \underset{\substack{\text{(Storm}\\\text{water}\\\text{Runoff)}}}{14240}) \times \underset{\substack{\text{(Units}\\\text{Conversion)}}}{2.45\text{x}10^6} \times \underset{\substack{\text{(Impound-}\\\text{ment}\\\text{Volume)}}}{\frac{1}{1.9\text{x}10^{11}}} = 0.22\ mgl^{-1}day^{-1}$$

Now, summing the two contributions:

$$k_a = k_{a(\text{algae})} + k_{a(\text{Trib})}$$

$$k_a = (.16,\ .21) + .22 = (.38,\ .43)\ mgl^{-1}day^{-1}$$

The value of k_1 will be assumed as 0.1 at 20^oC with θ in Equation (V-29) equal to 1.047. Then at 3.75^oC,

$$k_{1(3.75^oC)} = k_{1(20^oC)} \times 1.047^{(3.75-20)}$$

$$= .1 \times 1.047^{(-16.25)} = 0.047$$

Now $Q_{(discharge)}$ (mean for March and April) and V are known, with

$$Q_{(discharge)} = 26.8 \text{ (Swift River, Station 2)}$$

$$+ 6.2 \text{ (pumped withdrawal)} \times \frac{28.32\ell}{ft^3} = 935\ell \ sec^{-1}$$

$$V = 1.9 \times 10^{11}\ell$$

Then
$$C_{ss} = \frac{.38,\ .43}{(.03+.047+(935/1.9x10^{11}))} = 4.94,\ 5.58$$

For further computations, $C_{ss} = 5.25$ will be assumed.

Since k_s has been defined as .03, a steady-state areal concentration of benthic BOD prior to stratification can be estimated. If $k_{4(20^oC)} = .003$ and $C_{ss} = 5.25$, using Equation (V-34),

$$L_{ss} = \frac{k_s C_{ss} D}{k_{4(3.75^oC)}}$$

$$k_{4(3.75^oC)} = .003x1.047^{(3.75-20)} = .0014$$

$$L_{ss} = \frac{.03x5.25x6.7}{.0014} = 754 \ gm^{-2}$$

The next step in evaluating hypolimnion DO depression is to estimate pre-stratification DO levels. If we assume saturation at the mean temperature in April (5.5^oC), the dissolved oxygen concentration at onset of strata should be about 12.7 (from Table V-11).

Now we have all values needed to plot hypolimnion DO versus time using Equations (V-40) through (V-42).

Using $L_o = L_{ss}$

$C_o = C_{ss}$

$k_1 = 0.1 \times 1.047^{(9.5-20)} = .062$, ($T = 9.5^oC$ for May)

$k_s = 0.03$,

$k_4 = .003 \times 1.047^{(9.5-20)} = .002$, and

$t = 5$ days,

and applying Equation (V-42),

$$\Delta 0_c = \frac{k_1 C_{ss}}{k_1 + k_s} \left(1 - e^{-(k_1+k_s)t}\right)$$

$$\Delta 0_c = \frac{0.062 \times 5.25}{0.062 \times 0.03} \left(1 - e^{-(0.062+0.03)5}\right) = 1.30$$

Then, according to Equation (V-41),

$$\Delta 0_L = \left(\frac{L_{ss}}{D} + \frac{k_s C_{ss}}{k_s + k_1 - k_4}\right)\left(1 - e^{-k_4 t}\right) - \left(\frac{k_s C_{ss}}{k_s + k_1 - k_4}\right)\left(\frac{k_4}{k_s + k_1}\right)\left(1 - e^{-(k_s+k_1)t}\right)$$

$$\Delta 0_L = \left(\frac{754}{3.2} + \frac{0.03 \times 5.25}{0.03+0.062-0.002}\right)\left(1 - e^{-0.002 \times 5}\right) - \left(\frac{0.03 \times 5.25}{0.03+0.062-0.002}\right)$$

$$\left(\frac{0.002}{0.062+0.03}\right)\left(1 - e^{-(0.062+0.03)5}\right) = 2.35$$

Then from Equation (V-40)

$$0_t = 0_o - \Delta 0_c - \Delta 0_L$$

$$0_5 = 12.7 - \frac{3.32}{6.7} - 1.94 = 10.26$$

Solving the same equations with increasing t gives the data in Table V-15.

If it has been necessary to develop more data for the remainder of the stratified period, appropriately updated coefficients might be used starting at the beginning of each month.

TABLE V-15

DO SAG CURVE FOR QUIET LAKE HYPOLIMNION

Date	ΔO_L	ΔO_c	O_t
t = 0	0	0	0
5/5	2.35	1.30	9.05
5/10	4.68	2.13	5.89
5/15	6.99	2.65	3.06
5/20	9.22	2.98	0.50
5/25	11.54	3.18	0.00

Finally, if it is desired to evaluate the impact of altered BOD or phosphorus loadings, the user must go back to the appropriate step in the evaluation process and properly modify the loadings.

END OF EXAMPLE V-15

5.6 TOXIC CHEMICAL SUBSTANCES

Although reasonably accurate and precise methods have been prepared for screening only a few of the many priority pollutants (Hudson and Porcella, 1981), a reasonable approach for assessing priority pollutants in lakes based on the methods presented in Chapter 2 can be made if certain assumptions are made:

- The major processes affecting the fate and transport of toxicants in aquatic ecosystems are known.
- That reasonable safety factors are incorporated by making reasonable most case analyses.
- Because it is a screening approach, prioritization can be done to identify significant constituents, lakes where human health or ecological problems can realistically be expected, and processes which might require detailed study.

The major processes affecting toxicants are listed in Table V-16. The primary measure of the impact of a toxic chemical in a lake depends on its concentration in the water column. Thus, these screening methods are primarily directed at fate and transport of toxic chemicals. A secondary target is the concentration in aquatic biota, principally fish. Because of the complexity of various routes of exposure and bioaccumulation processes, the approach of bioconcentration is used to identify compounds likely to accumulate in fish. These can be applied to lakes using the following method:

- A fate model is used that incorporates sediment transport, sorption, partitioning, and sedimentation.
- Significant processes include the kinetic effects of sedimentation, volatilization and biodegradation.

TABLE V-16

SIGNIFICANT PROCESSES AFFECTING TOXIC SUBSTANCES IN AQUATIC ECOSYSTEMS

Physical-Chemical Processes	Rate Coefficient Symbol, time^{-1}
Sorption and sedimentation	SED
Volatilization	k_v
Hydrolysis	k_h
Photalysis	k_p
Oxidation	not assessed
Precipitation	not assessed
Biological Processes	
Biodegradation	B
Bioconcentration	BCF (unitless)

- Significant biochemical processes can affect the fate of a toxic chemical as well as affect biota, such, as, bioaccumulation, biodegradation, and toxicity.

- In keeping with the conservative approach of the toxics screening methodology, some important processes are neglected for simplicity; for example, lake stratification, photolysis, oxidation, hydrolysis, coagulation-flocculation, and precipitation are neglected. Also, it is assumed that the organic matter is associated with inorganic particles and therefore organic matter settles with the inorganic particles.

Generally the toxic chemical concentrations are calculated conservatively, that is, higher concentrations are calculated than would occur in nature because of the assumptions that are made. The water column concentrations are calculated as the primary focus of the screening method. Then bioconcentration is estimated, based on water concentration. To determine concentration and bioaccumulation, point and nonpoint source loadings of the chemicals being studied are needed. Other data (hydrology, sediments, morphology) are obtained from the problems previously done in earlier chapters or sections of this chapter. The person doing the screening would have to compile or calculate such data.

Occasionally, such information must be estimated based on production, use, and discharge data. Information on chemical and physical properties is important to determine the significance of these estimates.

5.6.1 Overall Processes

Several processes affecting distribution of toxic chemicals are more significant than others. Equilibrium aquatic processes include suspended sediment sorption of chemicals. Organics in sediments can have a significant effect on chemical sorption. Hydrolysis and acid-base equilibria can alter sorption equilibria. Volatilization is an equilibrium process that tends to remove toxic chemicals from aquatic ecosystems. Removal processes include settling of toxics sorbed on sediments, volatilization, and biodegradation. Chemical reactions for hydrolysis and photolysis are included and precipitation and redox reactions could be included if refinement of the method were desired. Generally, bioaccumulation will be neglected as a removal process.

These removal processes are treated as first-order reactions that are simply combined for a toxicant (C,mg/l) to give:

$$dC/dt = -K \times C \tag{V-44}$$

where

$K = SED + B + k_v + k_p + k_h$
SED = sedimentation rate, toxicant at equilibrium with sediments.
k_v = volatilization rate.
B = biodegradation rate.
k_p = photolysis rate.
k_h = hydrolysis rate.

This equation is analogous to the BOD decay rate equation used in the hypolimnetic DO screening method.

The input of toxic chemical substances is computed simply (refer to Figure V-23):

$$\frac{dC}{dt} = \frac{Q}{V} \times C_{in} - \frac{C}{\tau_w} \tag{V-45}$$

where C_{in} is the concentration in the inflow (tributary or discharge) and flow (Q), volume of reservoir (V) and time (t) are as defined previously.

At steady state, accounting for inflow ($Q \cdot C_{in}$) and outflow ($Q \cdot C$), and using $Q/V = 1/\tau_w$,

$$\frac{dC}{dt} = \frac{1}{\tau_w} (C_{in} - C) - K \times C = 0 \tag{V-46}$$

and solving,

$$C = C_{in}/(1 + \tau_w \times K) \tag{V-47}$$

To determine the concentration at any time during a non-steady state condition (assuming C is a constant):

$$C = \frac{C_{in}}{f}\ (1 - e^{-ft}) + C_o\ e^{-ft} \tag{V-48}$$

where

$f = 1 + \tau_w \times K$

C_o = reservoir concentration at t = 0.

5.6.1.1 Sorption and Sedimentation

Suspended sediment sorption is treated as an equilibrium reaction which includes partitioning between water (Cw) and the sediment organic phases (C_s). The concentration sorbed on sediment can be computed as follows:

$$\frac{Cs}{C} = a \times K_p \times S \tag{V-49}$$

where

C = the total concentration (Cw + Cs), mg/l

S = input suspended organic sediment = OC x So, mg/l

OC = fraction of organic carbon.

So = input of suspended sediment, mg/l

K_p = distribution coefficient between organic sediment and water

a = fraction of pollutant in solution

= $1/(1 + (K_p \times S)$

If K_p is large, essentially all of the compound will be sorbed onto the sediments. Note that S and C must be estimated or otherwise obtained.

The organic matter content of suspended sediment and the lipid solubility of the compound are important factors for certain organic chemicals. Other sorption can be ignored for screening. A simple linear expression can be used to calculate the sediment partition coefficient (K_p) based on the organic sediment carbon concentration (OC) and the octanol-water coefficient (kow) for the chemical:

$$K_p = 0.63\ (\text{kow})\ (\text{OC})$$

The sedimentation rate (SED) of a toxic chemical is computed as follows:

$$\text{SED} = a \times D \times K_p \qquad \text{(V-50)}$$

where

D = P x S x Q/V, sedimentation rate constant
P = sediment trapping efficiency
Q/V = $1/\tau_w$

5.6.1.2 Biodegradation

The biodegradation rate (B) is obtained from the literature or is computed as follows:

$$B = -\frac{\Delta C}{C\Delta t} \qquad \text{(V-51)}$$

Modification to the rate can be made for nutrient limitation using phosphorus (Cp) as the limiting nutrient:

$$B\ \text{limited} = \frac{B\ (0.0277)C_p}{1 + 0.177 \times C_p} \qquad \text{(V-52)}$$

Temperature correction can be performed using the following equation:

$$B(T) = B(20^{\circ}\text{C}) \times 1.072^{(T-20)} \qquad \text{(V-53)}$$

Previous exposure to the pollutant is important for most toxic organic compounds. Higher rates of degradation occur in environments with frequent or longterm loading (discharges, nonpoint sources, frequent spills) than infrequent loadings (one-time spills). In pristine areas, rates of one to two orders of magnitude less should be used.

It is assumed that the suspended sediment decay rate is the same as aqueous phase decay. Also benthic decay is disregarded because bottom sediment release may be negligible.

5.6.1.3 Volatilization

Many organics are not volatile so this process is applied only to those which are. It is assumed that the mass flux of volatile organics is directly proportional to the concentration difference between the actual concentration and the concentration at equilibrium with the atmosphere. The latter can be neglected in lakes. Also, only the most volatile are assessed.

Thus,

$$\frac{dC}{dt} = -k_v \times C \qquad \text{(V-54)}$$

where

k_v = volatilization rate constant, hr^{-1}

The rate coefficient is derived from the 2 resistance model for the liquid-gas interface, but it can be estimated using correlation with the oxygen reaeration coefficient (based on Zison *et al.*, 1978):

$$k = Ka \quad (Dw/Do) \qquad \text{(V-55)}$$

and estimate $(Dw/Do) = (32/mw)^{\frac{1}{2}}$

and the surface film thickness, $SFT = (200 - 60 \cdot \sqrt{w}) \times 10^{-6}$

and $Kal = Do/SFT$

$Ka = Kal/ZB$

where

Ka = reaeration rate, hr^{-1}

Dw = pollutant diffusivity in water

Do = diffusivity of oxygen in water (2.1×10^{-9} m^2/sec, 20^oC)
mw = pollutant molecular weight
W = wind speed, m/sec
$\bar{Z}$ = mean depth, m

The volatilization rate coefficient (k_v, hr^{-1}) is determined by $k_v = Ka \times k$ where k is obtained from literature values or computed as above ($\sqrt{Dw/Do}$). The rate should be corrected for temperature (k_{vt}) even though temperature has only a relatively small effect:

$$k_{vt} = k_v \times 1.024^{(T-20)} \quad \text{(V-56)}$$

5.6.1.4 Hydrolysis

Not all compounds hydrolyze and those that do can be divided into three groups: acid catalyzed, neutral, and base catalyzed reactants. A pseudo first-order hydrolysis constant (k_h) is estimated for the hydrolysis of the compound:

$$\frac{dC}{dt} = - k_h \cdot C \quad \text{(V-57)}$$

The rate constant (k_h) is pH dependent and varies as discussed in Chapter 2. The typical pH of the lake for the appropriate season should be obtained for the necessary calculations. Generally, the pH is a common measurement and is available for most lakes. If not, pH values for most open lakes lie between 6-9 and can be estimated based on the following empirical values based on Hutchinson, (1957):

	Hardness (or Alkalinity)	pH
acid lakes	<25	6 - 6.5
neutral lakes	25 - 75	6.5 - 7.5
hard water lakes	75 - 200	7.5 - 8.5
eutrophic and alkaline lakes	0 - 300	8.0 - 10.0

Median values on a range of values can be used to evaluate the significance of hydrolysis as a factor affecting the fate of compounds.

5.6.1.5 Photolysis

Generally, photolysis is a reaction between ultraviolet light (UV, 260 to 380 nm is most important) and photosensitive chemicals. Not all compounds are subject to photolysis nor does UV light penetrate significantly in turbid lakes. In the absence of turbidity data, light transmission can be estimated by seasonally averaged Secchi disk readings according to the following equation:

$$\ln (ISD/Io) = -ke(SD) \approx \ln 0.1 = -2.3$$
$$ke = 2.3/SD$$

where

ke is the extinction coefficient and
SD is the Secchi depth in meters.
$(ISD/Io = 0.1)$ is the relative intensity based on Hutchinson (1957).

Photolysis for appropriate chemicals (discussed in detail in Chapter 2) depends on a first order rate constant (k_p) incorporating environmental variables (solar iradiance, Io) and chemical variables (quantum yield, ϕ, and absorbance, E). Turbidity effects are included as estimated as above since turbidity data are generally not available. These values are incorporated into the rate constant and the concentration reduced as follows (details described in Chapter 2):

$$\frac{dC}{dt} = - k_p C \qquad \text{(V-58)}$$

where

$$k_r = f (Io, \phi, E, ke, \bar{Z})$$

and

$$kp = \frac{kr}{ke \cdot \bar{Z}}$$

where

k_r is the photolysis rate constant uncorrected for depth and turbidity of the lake.

Depth (Z) is generally applied only to the photic zone and mean depth ($\bar{Z}$) is an appropriate measure since it approximates the mixed depth and the photic zone.

5.6.1.6 Bioconcentration

Bioconcentration is a complex subject that depends on many variables. The simplest approach has been developed for organic compounds using the octanol-water coefficient (kow) to calculate tissue concentrations (Y):

$$Y = BCF \times C, \text{ g/kg fresh weight of fish flesh.} \qquad \text{(V-59)}$$

where BCF = Bioconcentration factor and log BCF = 0.75 log kow - 0.23, (The coefficients for the equation (0.75, - 0.23) are median estimates obtained from correlation equations and are default values for occasions where no other data are available.)

5.6.2 Guidelines for Toxics Screening

Generally metals do not biodegrade nor volatilize. However, pH, hardness, alkalinity and other ions are very important and can cause their removal by precipitation. The conservative approach is taken here and metals are calculated without removal (K = 0).

Organics may have variable sorption, volatilization, and biodegradation rates. If data are available in the literature, these should be used. Otherwise, a conservative approach should be used and calculations made without removal (K = 0). For chlorinated (and other halogens) compounds or refractory compounds, biodegradation should be assumed to be zero.

EXAMPLE V-16

Estimating Trichloroethylene and Pyrene Concentrations in an Impoundment

An impoundment with a single tributary is located in a windy valley. The following conditions are known for E.G. Lake:

Mean tributary flow rate = 3.6×10^4 m^3 /hour
Total volume = 1.1×10^8 m^3
Mean depth = 11 m
Tributary average sediment load = 200 mg/l
Sediment average organic carbon content = .05
Inlet average pyrene concentration = 50 ug/l
Inlet average trichloroethylene concentration = 100 ug/l
Lake average phosphorus concentration = 50 ug/l
Mean water temperature = 15^oC
Mean wind speed = 6 m/sec (35 mph)
Secchi depth = 1 m

Determine the steady state concentration of pyrene and trichloroethylene in the lake, assuming V max for the sediment (mostly clay) is 3.2×10^{-5} feet/second. The trapping efficiency is obtained from Figure V-33.

Other data	Pyrene	Trichloroethylene
kow	148000	190
B	$1x10^{-4}$	-
k_v	-	0.45xKa

The processes of photolysis and hydrolysis can be neglected because turbidity prevents photolysis (SD = 1 meter) and these compounds have negligible hydrolysis (see Chapter 2).

We use the summary equation (V-47) for the analysis:

$$C = C_{in}/(1 + \tau_w \cdot K)$$

The hydraulic residence time of E.G. Lake is:

$$\begin{aligned}\tau_w &= 1.1 \times 10^8 \text{ m}^3/(3.6 \times 10^4 \text{m}^3/\text{hr})\\ &= 3048 \text{ hours}\\ &= 127 \text{ days}\\ &= .349 \text{ year}\\ &= 1.1 \times 10^6 \text{ seconds}\end{aligned}$$

Sedimentation

First, the suspended sediment concentration in E.G. Lake must be estimated. The trapping efficiency of the impoundment is estimated from Figure V-34.

Data:

		log 10
V max	$= 5 \times 10^{-6}$ fps	-5.30
τ_w	$= 1.1 \times 10^6$ sec	6.04
D^1	= 11 m = 36.1 ft	1.56

A value of $10^{1.95}$ is obtained which yields

$$P \cong 90 \quad = \quad 0.9$$

In the inflowing stream, the toxicants are assumed to be at equilibrium with the organic matter. Thus,

$$S = OC \times So = .05 \times 200 \times 10^{-6} \qquad = 1 \times 10^{-5} \text{ kg/l}$$

Therefore, for pyrene

$$K_p = 0.63 \times 148000 \times 0.05 = 4660$$

$$a = 1/(1 + 4660 \times 1 \times 10^{-5}) = 0.955$$

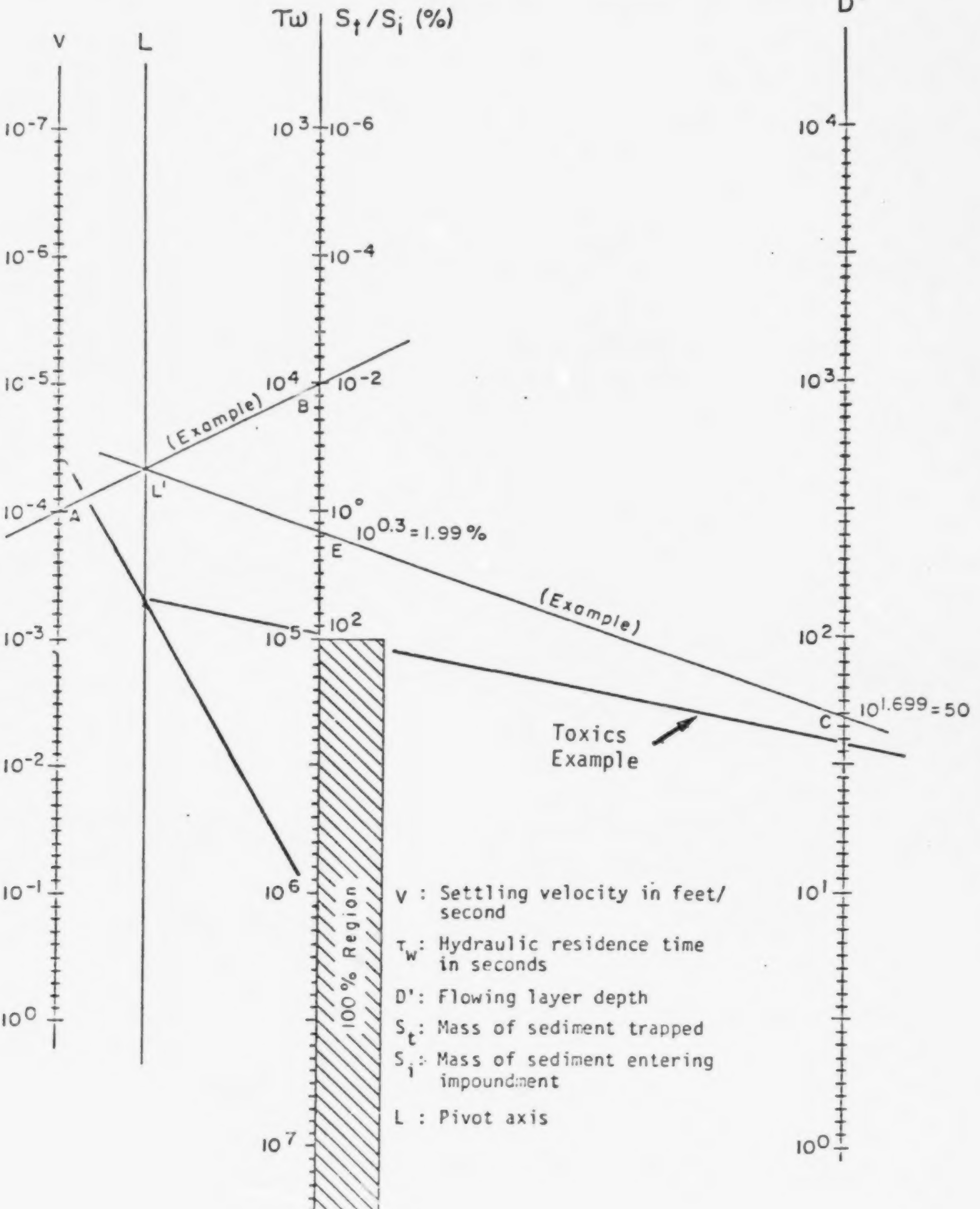


FIGURE V-34 NOMOGRAPH FOR ESTIMATING SEDIMENT TRAP EFFICIENCY

$$\frac{Cs}{C} = 0.955 \times 4660 \times 1 \times 10^{-5} = 0.044$$

and

$$SED = a \times D \times K_p$$

$$D = P \times S \times Q/V$$

$$D = 0.9 \times 200 \times 10^{-6} \times \frac{1}{3048} \text{ hours}$$

$$D = 5.91 \times 10^{-8} \text{ hour}$$

$$SED = .955 \times 5.91 \times 10^{-8} \times 4660$$

$$SED = 2.63 \times 10^{-4} \text{ hr}^{-1}$$

For trichloroethylene

$$K_p = .63 \times 190 \times 1 \times .05 = 6$$

$$a = 1/(1 + 6 \times 1 \times 10 \quad) = 1$$

$$\frac{Cs}{C} = 1 \times 6 \times 1 \times 10^{-5} = 6 \times 10^{-5} \cong 0$$

and

$$SED = 1 \times 5.91 \times 10^{-8} \times 6$$

$$SED = 3.54 \times 10^{-7} \text{ hr}^{-1}$$

Biodegradation

Assume that the presence of trichloroethylene does not affect the biodegradation of pyrene. Trichloroethylene does not biodegrade. The temperature corrected and nutrient limited rate constant for microbial decay of pyrene are:

$$Bo = 1.\ x\ 10^{-4}\ hr^{-1}$$

$$B = .0277\ x\ 50/\ (1 + .0277\ x\ 50)$$

$$= .58$$

$$B(15) = .58x\ 1.\ x\ 10^{-4}\ x\ 1.072^{(15-20)}$$

$$= 4.1\ x\ 10^{-5}\ hr^{-1}$$

Volatilization

The reaeration coefficient for E.G. Lake will be estimated for trichloroethylene only, because pyrene does not volatilize:

$$Kal = 2.1\ x\ 10^{-9}\ /\ (200 - 60\ x\ 6^{\frac{1}{2}})\ 10^{-6}$$

$$= 3.96\ x\ 10^{-5}\ m/sec$$

$$= .143\ m/hr$$

$$Ka = (.143\ m/hr)\ /\ 11\ m = .013\ hr^{-1}$$

For trichloroethylene (TCE):

$$k_v = [MW(TCE)/MW(O_2)]^{\frac{1}{2}} \cdot Ka = .45\ x\ .013 = .0058\ hr^{-1}$$

When adjusted for temperature:

$$k_v = .0058\ x\ 1.024^{(15-20)}$$

$$= .0052\ hr^{-1}$$

Volatilization for pyrene may be neglected.

Pollutant Mass Balance

The overall decay rate constants are: $K = SED + B + k_v$

Pyrene: $K = 2.63 \times 10^{-4} + 4.1 \times 10^{-5}$

$= .000304\ hr^{-1}$

Trichloroethylene: $K = 3.54 \times 10^{-7} + 0 + 0.0051$

$= .0052\ hr^{-1}$

Using the steady state equation:

$$C = C_{in} / (1 + \tau_w K)$$

For Pyrene

$$C = 50\ \mu g/l\ /\ (1 + 3048\ hr \times .000304\ hr^{-1})$$

$$C = 27\ \mu g/l$$

Note: WQC for human health is 0.0028 μg/l at 10^{-6} Risk (FR: 11/28/80 p. 79339).

For Trichloroethylene

$$C = 100\ \mu g/l\ /\ (1 + 3048\ hr \times .0052\ hr^{-1})$$

$$= 5.9\ \mu g/l$$

Note: WQC for human health is 2.7 μg/l at 10^{-6} Risk (FR: 11/28/80 p. 79341)

Tissue burdens (Y) can be calculated:

$$Y = BCF \times C$$

where

$$\log BCF = .75 \log kow - 0.23$$

For Pyrene

$$Y = 4330 \times 27 = 120000 \ \mu g/kg \text{ fish flesh}$$

For Trichloroethylene

$$Y = 30 \times 6 = 180 \ \mu g/kg \text{ fish flesh}$$

Comments

Several conclusions are apparent from this analysis

- Certain processes dominate the overall fate for a specific toxic chemical so that, practically speaking, errors in estimating coefficients are negligible except for the important processes. After identifying the important processes, the coefficients can be varied to determine the range of concentrations. For example, sedimentation of trichloroethylene can be ignored; however, volatilization should be studied.

- The more stringent Water Quality Criteria are for toxicants that have significant bioconcentration; e.g. compare pyrene to trichloroethylene.

- Volatilization of trichloroethylene would be investigated in detail since this process might not be significant in this lake because of its depth. Also, the physical properties are important; e.g. trichloroethylene has a specific gravity of about 1.5. Thus, it may accumulate on the bottom of the reservoir and remain there unless it is completely dispersed.

- Based on this analysis, sources of pyrene would be assessed first, then trichloroethylene.
- What other observations can you draw from this analysis?

END OF EXAMPLE V-16

5.7 APPLICATION OF METHODS AND EXAMPLE PROBLEM

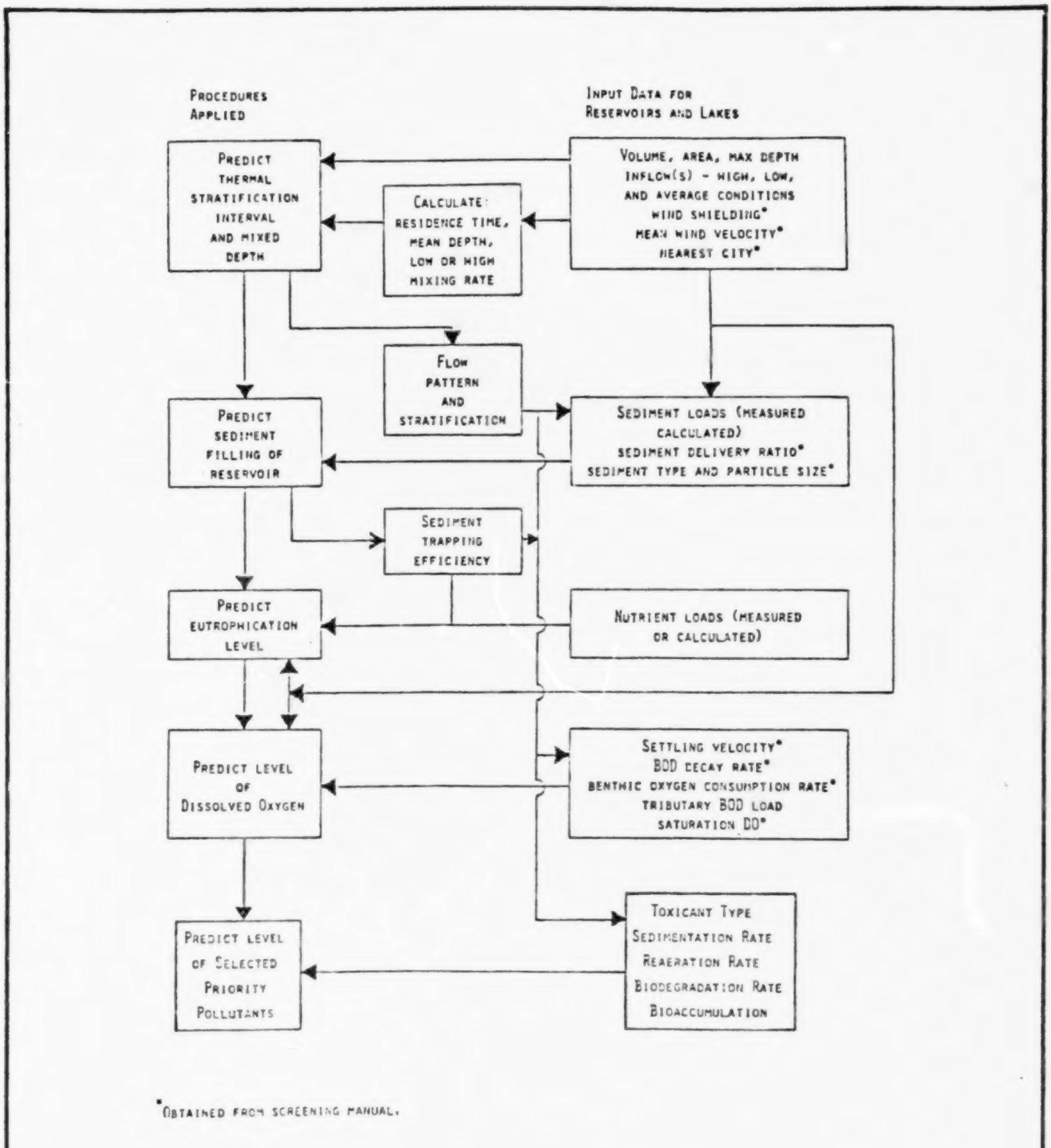
This chapter has presented several approaches to evaluation of five impoundment problem areas. These are thermal stratification, sediment accumulation, eutrophication, hypolimnion DO/BOD, and toxic chemicals. Figure V-35 shows how the different approaches are linked together with their data needs. In studying any or all of the potential problem areas in an impoundment, the user should first define the potential problems as clearly as he can. Often the nature of a problem will change entirely when its various facets are carefully described and examined *en masse*.

Once the decision is made that an aspect of impoundment water quality should be evaluated and the problem is clearly stated, the user should examine available solution techniques presented both in this document and elsewhere. The examination should address the questions of applicability, degree of accuracy, and need for data. The user will generally know what funds are available for data collection as well as the likelihood of procuring the needed data from previously developed bases. Also, the decision concerning needed accuracy rests with the user, and he should make decisions based upon the way in which his results will be used.

Once appropriate methods have been selected, the next task is to set down the data and to manipulate it according to computational requirements. Data are best displayed first in tabular form and then plotted in some meaningful way. Careful tabulation of data and graphing can themselves sometimes provide a solution to a problem, negating need for further analysis. To illustrate these steps, a comprehensive application to a river basin system was performed in this section.

5.7.1 THE OCCOQUAN RESERVOIR

The Occoquan River basin in Virginia was used to demonstrate the screening approach. A basin map is shown in Figure V-36. Because the Occoquan Reservoir is a public drinking water supply downstream from metropolitan areas, water quality data were available to compare to the screening method's outputs.


Procedures Applied
Input Data for Reservoirs and Lakes
Predict thermal stratification interval and mixed depth
Calculate: residence time, mean depth, low or high mixing rate
Volume, area, max depth inflow(s) - high, low, and average conditions wind shielding* mean wind velocity* nearest city*
Flow pattern and stratification
Predict sediment filling of reservoir
Sediment loads (measured calculated) sediment delivery ratio* sediment type and particle size*
Sediment trapping efficiency
Predict eutrophication level
Nutrient loads (measured or calculated)
Predict level of Dissolved Oxygen
Settling velocity* BOD decay rate* benthic oxygen consumption rate* tributary BOD load saturation DO*
Predict level of Selected Priority Pollutants
Toxicant Type Sedimentation Rate Reaeration Rate Biodegradation Rate Bioaccumulation

*Obtained from screening manual.

FIGURE V-35 GENERALIZED SCHEMATIC OF LAKE COMPUTATIONS

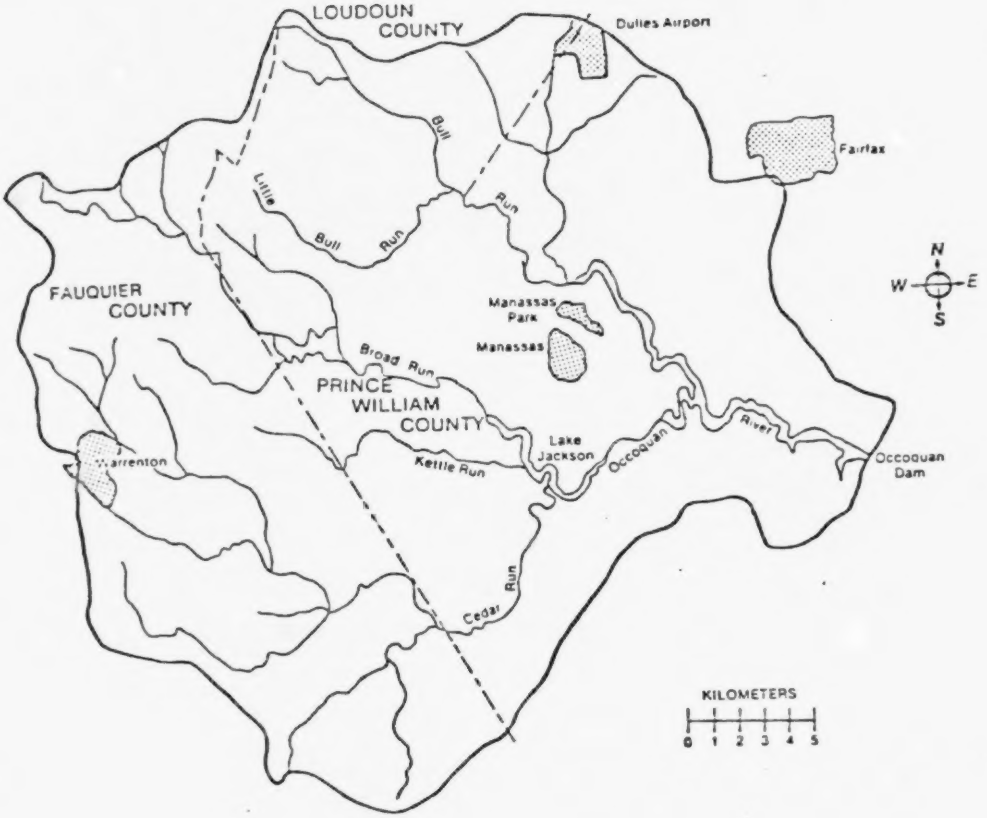


FIGURE V-36 THE OCCOQUAN RIVER BASIN

5.7.2 Stratification

Occoquan Reservoir is about 32 km southwest of Washington, D.C. and has the following morphometric characteristics:

Volume, m^3 = 3.71×10^7
Surface area, m^2 = 7.01×10^6
Maximum depth, m = 7.1 (Occoquan Dam)
Mean depth, m = 5.29

Based upon the above geometry and the thermal plots, determine whether the lake will stratify, the thickness of the epilimnion and the hypolimnion, the depth to the thermocline, and the interval and starting and ending date of stratification. Also note the temperature of the hypolimnion at the onset of stratification.

Predicting the extent of shielding from the wind requires use of topographic maps. The reservoir is situated among hills that rise 25 meters or more above the lake surface within 200 meters of the shore. The relief provides little access for wind to the lake surface. Average annual wind speeds are 15.6 km/hr in Washington, D.C. and 12.6 km/hr in Richmond, VA. Inflow comes essentially from two creeks, the Occoquan River and Bull Run River (Figure V-36).

First, determine needed information and then do metric/English conversions as necessary.

The first step in assessing impoundment water quality is to determine whether the impoundment thermally stratifies. This requires knowledge of local climate, impoundment geometry, and inflow rates. Using this information, thermal plots likely to reflect conditions in the prototype are selected from Appendix D.

For the thermal plots to realistically describe the thermal behavior of the prototype, the plots must be selected for a locale climatically similar to that of the area under study. Because the Occoquan Reservoir is within 32 kilometers of Washington, D.C., the Washington thermal plots (Appendix D) should best reflect the climatic conditions of the Occoquan watershed.

The second criterion for selecting a set of thermal plots is the degree of wind stress on the reservoir. This is determined by evaluating the amount of protection from wind afforded the reservoir and estimating the intensity of the local winds. Table V-2 shows annual wind speed frequency distribution for Washington, D.C. and Richmond, Virginia. The data suggest that winds in the Occoquan area are of moderate intensity.

Predicting the extent of shielding from the wind requires use of topographic maps. The reservoir is situated among hills that rise 25 meters or more above the lake surface within 200 meters of the shore. The relief provides little access for wind to the lake surface. The combinatiuon of shielding and moderate winds implies that low wind stress plots are appropriate.

The geometry of the reservoir is the third criterion used in the selection of thermal plots. Geometric data for the Occoquan Reservoir are summarized in the problem. The volume, surface area, and maximum depth are all nearly midway between the parameter values used in the 40-foot and 75-foot maximum-depth plots. However, the mean depth is much closer to the mean depth of the 40-foot plot.

The mean depth represents the ratio of the volume of the impoundment to its surface area. Because the volume and surface area are proportional to the thermal capacity and heat transfer rates respectively, the mean depth should be useful in characterizing the thermal response of the impoundment. It follows that the 40-foot thermal profiles should match the temperatures in the Occoquan Reservoir more closely than the 75-foot profiles. However, it is desirable to use both plots in order to bracket the actual temperature.

Flow data provide the final information needed to determine which thermal plots should be used. The inflow from the two tributaries adds up to be 20.09 m^3/sec.

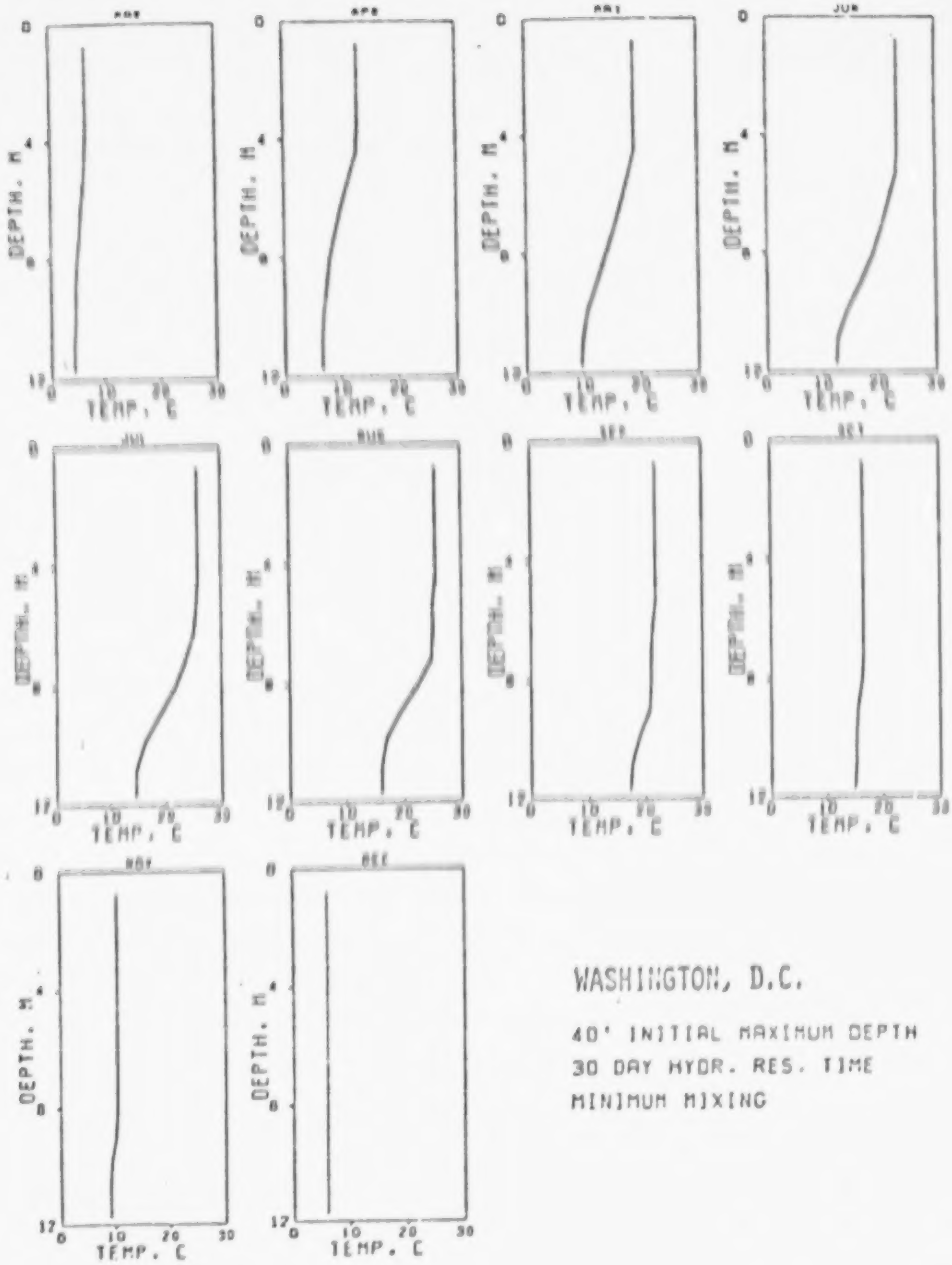
The hydraulic residence time can be estimated by using the expression:

$$\tau_w = \frac{V}{Q} = \frac{3.71 \times 10^7 \ m^3}{20.09 \ \frac{m^3}{sec} \times 86400 \ \frac{sec}{day}} = 21.4 \text{ days}$$

Since the residence time is midway between the thermal plot parameter values of 10 and 30 days, both should be used to bracket the mean hydraulic residence time in the prototype. It should be noted that these flow estimates do not include runoff from the area immediately around the lake. However, the upstream Occoquan watershed is large enough relative to the immediate runoff and direct precipitation to justify the assumption that the contribution of the immediate area is not significant.

The likelihood that the Occoquan Reservoir thermally stratifies can now be evaluated. For a hydraulic residence time of ten days, the thermal plots show that stratification is not likely for maximum depths of 40 to 75 feet. In the case of a 30-day hydraulic residence time, the profiles suggest that the reservoir develops a thermal gradient between $1^oC\ m^{-1}$ and $3^oC\ m^{-1}$ for either value of maximum impoundment depth. The 40-foot plots (Figure V-37) indicate stratification occurs from May to August at 5-7 meters depth. However, the 75-foot plots predict that the impoundment will have a thermal gradient greater than $1^oC\ m^{-1}$ only at depths greater than 17 meters. Since the Occoquan Reservoir is 17.1 meters deep at the deepest station, this suggests that the impoundment does not stratify.

The mean hydraulic residence time can be computed using either the average annual flow rate or the flow rate just prior to stratification. In order to use the latter method, the flow rate during the months of March and April should be computed. The flow rate for this period, 25.4 $m^3\ sec^{-1}$, reduces the hydraulic retention time to 17 days. Since the model predicts no stratification for a ten-day residence time, the judgment as to whether stratification occurs becomes difficult.



WASHINGTON, D.C.

40' INITIAL MAXIMUM DEPTH
30 DAY HYDR. RES. TIME
MINIMUM MIXING

FIGURE V-37 THERMAL PROFILE PLOTS FOR OCCOQUAN RESERVOIR

Because lower flows occur during the summer, the 30-day residence time, 40 foot depth and minimum mixing should be used. In borderline cases such as this, the reservoir will almost certainly stratify during some part of the summer.

The temperatures predicted by the thermal plots match those actually measured in the reservoir quite closely. A comparison of predicted and observed monthly mean temperatures (1974-1976) in both the epilimnion and hypolimnion can be made using observed data (Table V-17) and the plot of the 40 foot, 30 day residence time, minimum mixing (Figure V-37). The difference between the two epilimnion temperatures averages 1.0°C and varies between 0.2 and 1.8°C. The difference in the hypolimnion temperatures averages 1.0°C and ranges from 0.2 to 2.7°C.

The close agreement of the predicted and observed impoundment temperatures probably results from the relatively long hydraulic residence times observed in two of the three years on which the averages are based. In 1974, 1975, and 1976, the mean hydraulic residence times were 31, 18, and 25 days, respectively. The 30-day thermal plots should predict results relatively close to the two low-flow years. The differences expected for 1975 would be less pronounced when averaged with the other two.

In conclusion, Occoquan Reservoir does apparently stratify, the depth to the thermocline or the epilimnion approximates the mean depth (5.29), the hypolimnion has a depth of 11.8 m (17.1-5.3), and the interval of stratification approximates May 1 to mid September or 138 days. The hypolimnetic temperature is about 11 degrees C, typically.

5.7.3 Sedimentation

To evaluate potential sedimentation problems, Appendix F is examined to see if any data exist on the upstream reservoir (Jackson) or Occoquan Reservoir (Figure V-36). Some data exist for Jackson but not for Occoquan Reservoir (Figure V-38 taken from Appendix F). Thus, we can determine the trapping of sediment in Jackson Reservoir but trapping must be calculated

TABLE V-17

COMPARISON OF MODELED THERMAL PROFILES TO OBSERVED TEMPERATURES IN OCCOQUAN RESERVOIR

	Mean Epilimnion Temp.		Mean Hypolimnion Temp.		Epilimnion Depth (m)
Month	40-foot Plot (°C)[a]	Observed[c]	40-foot Plot (°C)[b]	Observed[c]	40-foot Plot[b]
March	7	8.4	6	6.3	--
April	13.5	12.6	10	9.2	--
May	19	20.5	15	14.4	4.5
June	24	24.8	18	17.2	5.0
July	26	26.6	20	21.2	6.5
August	26	26.5	21	23.7	7
September	22	23.8	20	20.2	--
October	17	17.2	16	15.8	--
November	11	12.2	10	11.6	--
December	7	6.2	7	5.8	--

[a] Mean temperatures in epilimnion from thermal plots with τ_W = 30 days and a maximum depth of 40 feet.

[b] Mean temperatures in thermocline and hypolimnion from thermal plots with τ_W = 30 days and a maximum depth of 40 feet.

[c] Means of observed temperatures in "upper" and "lower" layers of Occoquan Reservoir for 1974-1976, at Sandy Run.

Source: Northern Virginia Planning District Commission, January , 1979.

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY		PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET							AC.-FT.	TONS	
				POTOMAC, RAPPAHANNOCK, YORK, AND JAMES RIVER BASINS										
5-1a	Lake Barcroft	Trib. of Potomac River	Falls Church, Va.	14.5	14.3	Jan.	1915	—	8/1,847	.142	—	—	—	SCS
	-do-	-do-	-do-	—	—	Feb.	1938	23.1	8/1,762	.134	*60	.257	336	
	-do-	-do-	-do-	—	—	Aug.	1957	19.5	9/2,092	.161	—	.728	950	
5-2	Pedlar	Pedlar River	Oronoco, Va.	33.21	33.07	Feb.	1907	—	1,860	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Feb.	1938	31	1,723	—	—	.134	—	
5-3	Burnt Mills	N. W. Br. Anacostia River	Silver Spring, Md.	27.0	26.97	May	1930	—	181	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Mar.	1938	7.8	95	—	*60	.408	533	
5-4b	Greenbelt Lake	Trib. of Indian Creek	Greenbelt, Md.	10/.82	.79	July	1936	—	196	*.312	—	—	—	SCS
	-do-	-do-	-do-	—	—	Feb.	1938	1.6	186	*.296	*60	7.91	10,337	
	-do-	-do-	-do-	—	—	Aug.	1957	19.5	151	*.240	*60	2.27	2,970	
	-do-	-do-	-do-	—	—	June	1968	10.8	11/147	.234	*60	1.52	1,945	
5-5a	Staunton	North River	Staunton, Va.	25	25	Dec.	1925	—	385	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Jan.	1940	14	373	—	—	.034	—	
	-do-	-do-	-do-	—	—	June	1957	17.5	350	—	—	.053	—	
5-6	Jackson	Occoquan Creek	Manassas, Va.	337	336.4	July	1930	—	4,500	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug.	1937	7.2	4,158	—	*60	.162	184	
5-7b	Triadelphia L. (Brighton D.)	Patuxent River	Brighton, Md.	81.4	80.0	Jan.	1942	—	12/20,222	.327	—	—	—	SCS
	-do-	-do-	-do-	—	—	Oct.	1950	8.3	20,089	.324	*50	.20	218	
	-do-	-do-	-do-	—	—	Sept.	1958	7.9	19,633	.317	*50	.72	784	
	-do-	-do-	-do-	—	—	Aug.	1964	5.9	19,045	.308	61.1	1.25	1,663	
5-8	Gordon Lake	Evitts Creek	Cumberland, Md.	64	13/4	Sept.	1913	—	3,129	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Apr.	1940	26.6	3,004	—	—	14/.090	—	
5-9	Thomas W. Koon Lake	-do-	-do-	60	59.6	Mar.	1932	—	7,312	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Apr.	1940	8.1	7,294	—	—	.036	—	
5-10	Savage River Dam	Savage River	Bloomington, Md.	105.0	104.44	Mar.	1952	—	20,300	.172	—	—	—	SCS
	-do-	-do-	-do-	—	—	Mar.	1956	4.0	20,020	.169	*60	.643	840	
5-11	Rocky Gorge	Patuxent River	Laurel, Md.	132.8	50.14	Mar.	1954	—	21,390	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug.	1964	10.4	20,789	—	67	1.15	1,678	
5-12	South River, Site 26	Inch Branch	Waynesboro, Va.	2.7	2.7	May	1956	—	610.4	.28	—	—	—	SCS
	-do-	-do-	-do-	—	—	Nov.	1970	14.5	607.0	.28	*60	.087	110	
5-13	Wilde Lake	Trib. Little Patuxent	Columbia, Md.	1.88	1.85	Sept.	1966	—	196.97	.140	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug.	1968	1.9	170.99	.122	*60	15/7.39	16/11,278	
	-do-	-do-	-do-	—	—	Aug.	1969	1.0	163.72	.117	*60	3.93	5,133	
				CHOWAN, ROANOKE, TAR, NEUSE, AND CAPE FEAR RIVER BASINS										
6-1	Lake Apex	Swift Creek	Apex, N. C.	4.0	4.0	—	1925	—	106	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	June	1941	16	94	—	—	.19	—	
6-2	Franklinton	Sallie Keaney Creek	Franklinton, N. C.	1.13	1.12	Jan.	1925	—	34.7	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	May	1938	13.3	27.3	—	67	.509	743	
6-3	Greensboro (L. Brandt)	Reedy Fork	Greensboro, N. C.	74.1	73.4	Feb.	1923	—	2,870	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug.	1934	11.5	2,610	—	*60	.308	402	
6-4	High Point	Deep River	High Point, N. C.	62.8	62.3	Jan.	1928	—	4,354	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug.	1934	6.5	4,135	—	50.6	.541	596	
	-do-	-do-	-do-	—	—	Apr.	1938	3.75	4,038	—	—	.416	458	

1/ Includes estimated 112 acre-feet passing through Shandaken Tunnel.
2/ Includes 103 acre-feet of sediment dredged in 1937-1939.
3/ Partial survey covering segments 1-14 in Stoney Brook Arm Only.
4/ Net sediment contributing area was 299.4 sq. mi. until 1933 when Prettyboy Dam was completed. This area was used in the 1963 calculations.
5/ Revised after 1961 survey.
6/ Conservation or sediment pool only.
7/ Not determined - assumed equal to that determined in 1963.
8/ Based on original spillway crest elevation 205 feet m. s. l.
9/ Based on spillway crest elevation 210 feet m. s. l. and estimated capacity of 2,380 acre-feet resulting from 1962 addition to top of dam.
10/ Revised 1968.
11/ 9 acre-feet gained by dredging.
12/ Revised due to movable control gates.
13/ Koon Lake, upstream, was built in 1932.
14/ Based on total sediment in both Gordon Lake and Koon Lake.
15/ Does not include 4.34 acre-feet dredged.
16/ Includes 4.34 acre-feet dredged in early spring 1968.
* Estimated or assumed.

FIGURE V-38 SUMMARY OF RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

for the Occoquan. To refine the analysis, calculations on Jackson Reservoir will also be made and the results calibrated.

To apply the Stokes' law approach to a reservoir, we need to know the loading first. The necessary sediment loading estimates for the tributaries were provided by the methods in Chapter 3 and are listed in Table V-18 (Dean *et al*., 1980) Before they are used in further computations, a delivery factor must be applied to these values. This factor (the sediment delivery ratio or SDR) accounts for the fact that not all the sediment removed from the land surface actually reaches the watershed outlet. Nonpoint loads from urban sources are presumed to enter the reservoir through Bull Run River since most of the urbanized portion of the watershed lies in this sub-basin.

Computing the annual sediment load into Occoquan Reservoir is complicated by the presence of Lake Jackson immediately upstream from the reservoir. The trap efficiency must be computed for Lake Jackson as well in order to determine the amount of sediment entering the Occoquan Reservoir from Lake Jackson. The steps involved are to compute the sediment delivered (Table V-19), the size range, the fraction trapped for each size range and the total amount trapped. A table has been devised to simplify these steps (Table V-20).

Soil types provide an indication of the particle sizes in the basin under study. Soils in the Occoquan basin are predominately silt loams. Particle size data on the principal variety, Penn silt loam, are given in Table V-21. These data and all calculations are transcribed into Table V-22.

Some effort can be conserved by first calculating the smallest particle size that will be completely trapped in the impoundment. To do so, P, the trap efficiency, must first be computed. Because both reservoirs are long and narrow and have relatively small residence times, the flow will be assumed to approximate vertically mixed plug flow (Case B1). In this case, P is found from the expression:

TABLE V-18

ANNUAL SEDIMENT AND POLLUTANT LOADS IN OCCOQUAN WATERSHED IN METRIC TONS PER YEAR[a)]

Type of Load	Kettle Run	Cedar Run	Broad Run	Bull Run	Occoquan River	Urban Runoff
Sediment	46,898	396,312	142,241	232,103	139,685	12,699
Total Nitrogen	164.46	1,457.42	518.91	789.24	469.46	12.88
Available Nitrogen	16.45	145.74	51.89	78.92	46.05	5.38
Total Phosphorus	39.01	341.95	114.22	202.71	119.42	2.59
Available Phosphorus	2.18	14.95	5.57	12.50	8.43	1.27
BOD_5	328.92	2,925.63	1,042.45	1,578.47	925.85	77.47
Rainfall Nitrogen	0.72	5.50	2.00	3.92	2.48	-

[a)] Estimates provided by Midwest Research Institutes Nonpoint Source Calculator. These values have not yet had a sediment delivery ratio (SDR) applied to them. We will use 0.1 and 0.2 as lower and upper bounds. The SDR does not apply to rainfall nitrogen.

Note: A large number of significant figures have been retained in these values to ensure the accuracy of later calculations.

TABLE V-19

SEDIMENT LOADED INTO LAKE JACKSON, 1,000 KG/YEAR

TRIBUTARIES TO LAKE JACKSON	TOTAL AVAILABLE SEDIMENT	SEDIMENT DELIVERED TO LAKE JACKSON	
		CASE I (SDR=0.1)	CASE II (SDR=0.2)
KETTLE RUN	46,898	4,690	9,380
CEDAR RUN	396,312	39,630	79,260
BROAD RUN	142,241	14,220	28,440
TOTAL		58,540	117,080

TABLE V-20

CALCULATION FORMAT FOR DETERMINING SEDIMENT ACCUMULATION IN RESERVOIRS (NOTE UNITS)

Size Fraction	Percent Composition	Density		Mean Particle Diameter	V_{max}	Fraction Trapped (P)		Test Case	Incoming Sediment	Trapped Sediment
		Absolute	Bulk			A	B			

TABLE V-21

PARTICLE SIZES IN PENN SILT LOAM

Particle Size (mm)	% of Particles Smaller Than (By Weight)
4.76	100
2.00	99
0.42	93
0.074	84
0.05	78
0.02	50
0.005	26
0.002	16

TABLE V-22

CALCULATION FORMAT FOR DETERMINING SEDIMENT ACCUMULATION IN RESERVOIRS (NOTE UNITS)

Size Fraction	Percent Composition	Density		Mean Particle Diameter	V_{max}	Fraction Trapped (P)		Test Case	m ton/yr		
		Absolute	Bulk			A	B		Incoming Sediment	Trapped Sediment	
cin					m/day						m^3/yr
.000514	0.3	2.66	2.24	N/A	1.90	N/A	1.00	I	176	176	79
								II	352	352	158
.00050	5	2.66	2.24	N/A	1.79	N/A	0.94	I	2927	2751	1228
								II	5854	5502	1356
.00035	5	2.66	2.24	N/A	0.88	N/A	0.46	I	2927		601
								II	5854	2582	1209
.00020	16	2.66	1.28	N/A	0.29	N/A	0.15	I	9366	1405	1098
								II	18732	2810	2196
>.000518	73.7	2.66	2.33 (average)	N/A	-	N/A	1.00	I	43144	43144	19000
								II	86288	86288	37000
					Totals Trapped			I mtons/yr	48822		
								II mtons/yr	97644		
								I m^3/yr	21523		
								II m^3/yr	43046		

Example Calculation

SDR = 0.115

Vol = 24750 m^3/yr

Vol of Jackson Reservoir last per year = $\frac{24750\ m^3/yr}{1893000\ m^3}$ = 1.3%/year

(75 yrs lifetime)

$$P = \frac{V_{max}\ \tau_w}{D'}$$

where D' = mean flowing layer depth, m.

To calculate the smallest particle that is trapped in the impoundment, P is set equal to unity and the above equation is solved for V_{max}.

$$V_{max} = \frac{D' \cdot 1.0}{\tau_w}$$

This expression for V_{max} is then substituted into the fall velocity equation (Stokes' law), which in turn is solved for d.

$$V_{max} = \frac{4.8 \times 10^6\ (D_p - D_w)\ d^2}{\mu} = \frac{D'}{\tau_w}$$

The resulting expression is:

$$d = \sqrt{\frac{D'\ \mu}{4.8 \times 10^6\ (D_p - D_w) \cdot \tau_w}}$$

The trap efficiency of Lake Jackson is calculated first. The data required for these calculations are:

$V = 1.893 \times 10^6\ m^3$

$Q = 12.47\ m^3\ sec^{-1}$

$\bar{D} = 3.34\ m$

$\mu = 1.11$ (Assuming T = 16^oC as in Occoquan Reservoir)

and $\tau_w = \frac{V}{Q} = \frac{1.893 \times 10^6\ m^3}{12.47\ m^3 \cdot sec^{-1} \cdot 86400\ sec \cdot day^{-1}} = 1.76$ days

The minimum particle size for 100 percent trapping is computed as:

$$d = \sqrt{\frac{3.34\ m \times 1.11}{4.8 \times 10^6\ (2.66 - 1.0) \cdot 1.76}} = 5.14 \times 10^{-4}\ cm$$

The amount trapped of each size fraction is computed separately for Case B-1 from the equation

$$P = \frac{V_{max}\ \tau_w}{D'}$$

For example, for size fraction 0.00035 cm,

$$P = \frac{(0.88)(1.76)}{(3.34)} = 0.46$$

A composite trapping efficiency can be obtained by determining the total percent trapped (48822/58540 = 0.83).

The sediment accumulated in Lake Jackson for each size range is determined from the expression:

$$S_t = P \cdot S_i$$

where

P = trap efficiency
S_i = sediment load from tributary i
S_t = sediment trapped

For the two cases (I, II):

$$\begin{aligned} S_t &= (0.1,\ 0.1) \times 0.83\ [46898 + 132241] \text{ metric tons/year} \\ &= (48822,\ 97644) \text{ metric tons/year.} \end{aligned}$$

Data obtained from Appendix F of the screening manual show that the estimated rate of sedimentation in Lake Jackson is 56,153 metric tons/year. This indicates that an SDR of 0.115 would be appropriate.

Bulk density (g/cc) includes the water that fills pore spaces in sediment that has settled to the bottom and this must be accounted for when determining volume lost due to sedimentation. Bulk density varies with particle size and some approximate values for the size ranges for sand (0.005-0.2 cm), silt (0.0002-0.005 cm), and clay (<0.0002 cm) are as follows: 2.56 for sand, 2.24 for silt and 1.28 for clay. Thus, using an

SDR of .115, 24,750 m^3 (or 1.3%) of reservoir volume would be lost per year. In comparing to Appendix F data, we find that this value is conservative. The loss of volume was estimated by the SCS to be 47.5 acre feet/year while these calculations show only 20 acre feet/year being lost. The estimated bulk density used by the SCS was 0.93 g/cc and we used a more conservative value. If the SCS figure is used, the volume lost is determined to be 46.4 acre feet/year.

Now we compute the sedimentation in Occoquan Reservoir. The minimum particle size that is completely trapped is computed using the following values:

$D' = 5.29$
$\mu = 1.11$ (T = 16°C = mean of Table V-17)
$D_w = 2.66 \text{ g cm}^{-3}$
$D_w = 1.0 \text{ g cm}^{-3}$
$\tau_w = 21.4$ days

Under stratified conditions, the epilimnion thickness should be used for D'. Since stratification is uncertain in this case and the predicted average hypolimnion thickness, 5.75 m, is greater than the mean depth, the latter value will be used. All particles with diameter, d, such that:

$$d = \sqrt{\frac{5.29 \times 1.11}{4.8 \times 10^6 \; (2.66 - 1.0) \cdot 21.4}} = 1.86 \times 10^{-4} \text{ cm}$$

will be completely trapped in the Occoquan Reservoir. Because this value is smaller than the smallest size calculated for Lake Jackson (2×10^{-4} cm), our computations are simple. We assumed that 84 percent of the sediment is totally trapped and the remainder is trapped at an efficiency calculated for particle sizes of 0.0001 cm:

$$V_{max} = \frac{4.8 \times 10^6 \; (2.66 - 1.) \; (1 \times 10^{-4})^2}{1.11}$$

$$= 0.072 \text{ m/day}$$

$$P = \frac{V_{max} \cdot \tau_w}{D'} = \frac{0.072 \cdot 21.4}{5.29} = 0.29$$

The annual sediment trapped is

$$S_t = P \cdot S_i$$

but corrections for sources and SDR must be made:

S_i = SDR x sediment from each source.

S_i = 13390 (Lake Jackson, already corrected for SDR)
0.115 (232103) (Bull Run) + 0.115 (139685)
(Occoquan River) + 12699 (Urban Runoff)

S_i = 68845 metric tons/year

Assuming the distribution of particle sizes for all sources are essentially the same and accounting for the fractions (f) of material that are in the two different size ranges:

$$S_i = f_1 \; P_1 \; S_i + f_2 \; P_2 \; S_i$$

$$S_t = (0.84)\;(1.0)(68845) + (0.16)\;(0.29)\;(68845)$$

$$S_t = 57830 + 3194 = 61024 \text{ metric tons}$$

The volume lost is $\frac{61024}{0.93}$ = 65620 m³/year or 0.2 percent per year of the reservoir volume.

5.7.4 Eutrophication

What would be the consequences to eutrophication in Occoquan Reservoir of instituting 90 percent phosphorus removal at the treatment plant? If, in addition to phosphorus removal, nonpoint source (NPS) phosphorus was reduced by 90 percent by instituting urban runoff and erosion control, green belts, and other NPS controls, would an improvement in lake quality occur?

Several assumptions concerning pollutants in the Occoquan watershed-reservoir system are necessary in order to calculate the desired annual loads:

- The unavailable phosphorus is adsorbed on sediment particles. Therefore, of the unavailable forms coming into Lake Jackson, only the fraction (1 - P_c [Jackson]) is delivered to the Occoquan Reservoir; Available P gets through Jackson.

- All of the phosphorus and nitrogen from the sewage treatment plants (STPs) is in available form;

- The output of STPs outside the Bull Run sub-basin is negligible compared to that of the STPs in Bull Run. This is justified by the fact that during the period: under study, the plants in Bull Run had a combined capacity several times larger than the few plants outside the sub-basin.

- The problems of eutrophication depend on loading of phosphorus.

By applying these assumptions to the nonpoint source data in Tables V-18 and V-23 the total load of each pollutant type may be calculated (Table V-24). The computation for the total annual phosphorus load in Occoquan Reservoir is computed in the following paragraphs. First the quantity of total phosphorus coming into the Occoquan Reservoir through Lake Jackson is calculated by:

$$TP_{Jackson} = (1 - P_{c_{Jackson}}) \times [\text{Total P} - \text{Available P}] + \text{Available P}$$

The total phosphorus from Broad Run, Cedar Run, and Kettle Run are summed and the available phosphorus loads are subtracted to give the unavailable load. This load is multiplied by the trap efficiency of the lake, $P_c = 0.83$, which yields the unavailable load passing through. This value, plus the available load, is an estimate of the total phosphorus entering Occoquan Reservoir from Lake Jackson. This quantity is 103.24 metric tons yr^{-1}(Table V-24). This value is aded to the non-urban, nonpoint source

TABLE V-23

SEWAGE TREATMENT PLANT POLLUTANT LOADS IN BULL RUN SUB-BASIN IN METRIC TONS PER YEAR[a)]

Total Nitrogen	Total Phosphorus	BOD_5
108.0	11.92	54.80

[a/] Averages for July 1974 - December 1977

Source: Northern Virginia Planning District Commission, March 1979.

TABLE V-24

CALCULATED ANNUAL POLLUTANT LOADS TO OCCOQUAN RESERVOIR

Load Source	Metric Tons/Year				
	Total N	Avail.N	Total P	Avail.P	BOD_5
Urban runoff	12.88	5.38	2.59	1.27	77.47
Sewage treatment	108.00	108.00	11.92	11.92	54.80
Rainfall	14.62	14.62	-	-	-
Other Nonpoint Source*	391.00	39.10	48.83	2.65	802.00
TOTAL	526.50	167.10	63.34	15.84	934.27
Nonpoint Source %	80	35	81	25	94
Point Source %	20	65	19	75	6

* Used SDR of 0.115.

loads from Bull Run and areas adjacent to the Occoquan Reservoir (Table V-18):

$$\begin{aligned} TP_{NPNU} &= 202.71 + 119.42 + 103.24 \\ &= 425.37 \text{ metric tons yr}^{-1}. \end{aligned}$$

This quantity is modified by the sediment delivery ratio. The urban nonpoint loads and STP (Table V-24) loads are added to complete the calculation:

$$\begin{aligned} TP &= (0.115)\ (425) + 2.59 + 11.92 \\ &= 63.3 \text{ metric tons yr}^{-1}. \end{aligned}$$

Similarly the SDR was applied to nonpoint sources of nitrogen and BOD_5. The results of load calculations are summarized in Table V-24.

The calculated annual total phosphorus and nitrogen loads (Table V-24) may be compared with the observed loads listed in Table V-25. The loads observed are 1.5 to 6 times higher than highest calculated loads for nitrogen. Comparison of loadings (kg/ha year) with literature values suggest that Grizzard is most accurate (Likens et al., 1977).

The first method of predicting algal growth is known as the Vollenweider Relationship. In the graph of total phosphorus load (g m^{-2} yr^{-1}) versus mean depth (m) divided by hydraulic retention time (yrs) (see Figure V-24), areas can be defined that roughly correspond to the nutritional state of the impoundment. For the Occoquan Reservoir, the values of the parameters are:

$$L_p = \frac{(63.34) \times 10^6 \text{ g/yr}}{7.01 \times 10^6 \text{ m}^2} = 9.04 \text{ g m}^{-2} \text{ yr}^{-1}$$

$$\frac{\bar{Z}}{\tau_w} = \frac{5.29 \text{ m}}{0.0586 \text{ yr}} = 90 \text{ m yr}^{-1}$$

According to the Vollenweider Relationship, Occoquan Reservoir is well into the eutrophic region for loading of total phosphorus. Based on these predictions a more in-depth study of the algal productivity seems to be in order.

TABLE V-25

OBSERVED ANNUAL POLLUTANT LOADS TO OCCOQUAN RESERVOIR

Period	Mean Flow[a] Rate (m^3 sec^{-1})	Total Nitrogen Load (metric tons $year^{-1}$)	Total Phosphorus Load (metric tons $year^{-1}$)
10/74 - 9/75	24.7	805[b]	110[b]
7/75 - 6/76	24.0	1905[c]	188[c]
7/76 - 6/77	10.4	4763[c]	454[c]

[a] Source: USGS Regional Office, Richmond, Virginia.

[b] Grizzard et al., 1977

[c] Northern Virginia Planning District Commission, March, 1979. Data gathered by Occoquan Watershed Monitoring Laboratory.

Solving for the phosphorus concentration in this reservoir

$$P = \frac{Lp}{\bar{Z}} \quad \frac{1}{D+\sqrt{D}} = \frac{9.04 \text{ g m}^{-2}\text{ yr}^{-1}}{5.29\text{m}[(17.1+\sqrt{17.1})\text{yr}^{-1}]}$$

$$P = 0.0805 \text{ g/m}^3 = 80.5 \text{ µg/l.}$$

Calculated and observed pollutant concentrations are listed in Table V-26. The mean summer concentrations of phosphorus and nitrogen are closer to the concentrations calculated than would be expected on the basis of the comparison of annual loads.

The ratio of nitrogen to phosphorus concentration in the reservoir can be used to estimate which nutrient will limit the rate of plant growth. For the Occoquan Reservoir, the N:P ratios are 10 to 1 for total N to total P. The calculated nutrient ratios and the N:P ratio of the observed data (11.0) indicates that phosphorus is probably growth limiting.

The available data also permits the estimation of the maximal primary production of algae from the Chiaudani and Vighi Curve (Figure V-26). The theoretical phosphorus concentration should be about 0.08 g m^{-3} according to calculations. The maximal primary production of algae is found from Figure V-26 to be about 2500 mgC m^{-2} day^{-1} . This level of algal production is roughly the maximum production shown on the curve. Both this result and the Vollenweider Relationship suggest algal growth will contribute significantly to the BOD load in the impoundment.

- Effects of 90 percent P removal at treatment plant on TP loading:

$$M = 52.61 \text{ m ton/yr}$$

$$L = \frac{52.61 \times 10^6 \text{g/yr}}{7.01 \times 10^6 \text{ m}^2} = 7.50 \text{ g m}^{-2}\text{y}^{-1}$$

$$q_s = 90 \text{ m yr}^{-1}$$

TABLE V-26

CALCULATED AND OBSERVED MEAN ANNUAL POLLUTANT CONCENTRATIONS IN OCCOQUAN RESERVOIR

	Total Nitrogen[b] ($g\ m^{-3}$)	Available Nitrogen[a] ($g\ m^{-3}$)	Total Phosphorus ($g\ m^{-3}$)
Calculated (SDR = 0.115)	0.831	0.264	0.08
Observed Values[a]			
Mean	0.88	0.16	0.08
Max.	1.50	0.24	0.12
Min.	0.35	0.10	0.04

a)Assuming no removal processes for nitrogen.
b)Averages for April-October between 1973 and 1977.
Source: Northern Virginia Planning District Commission, March, 1979.

Although improved, we conclude that loading is still too great according to Figure V-24.

- Effects of 90 percent STP removal of TP plus 90 percent NPS removal of TP:

$$M = 6.334 \text{ m ton/yr}$$

$$L_p = \frac{6.334 \times 10^6}{7.01 \times 10^6} = 0.90 \text{ g m}^{-2} \text{ y}^{-1}$$

This would move Occoquan Reservoir into the bottom of the mesotrophic range.

- Lake concentrations of total P would be:

$$P = \frac{(7.5)}{(5.29) \cdot (21.2)} = 66.9 \ \mu g/l$$

$$P = \frac{0.90}{(5.19) \cdot (21.2)} = 8 \ \mu g/l$$

Although the screening method shows marked improvement in Occoquan eutrophication, 90 percent control of phosphorus NPS would be very expensive. Careful analysis of assumptions made in the screening method and of control alternatives would be necessary before proceeding to map such a control strategy. Moreover, careful study of reservoir TP sources and sinks and of algal productivity would be necessary. The screening method has served to illustrate the feasibility and potential value of such further analysis.

5.7.5 Hypolimnetic DO Depletion

Excessive nutrient loading plus inputs of BODs suggest that DO problems in the hypolimnion could result. We will use the data obtained in the first three problems to determine the hypolimnetic DO. These data are summarized below. All rate coefficients listed have already been corrected for temperature.

Physical/Biological

Area = $7.01 \times 10^6 \text{ m}^2$

Volume = $3.71 \times 10^7 \text{ m}^3$

$Q = 20.09 \text{ m}^3 \text{ sec}^{-1} = 1.74 \times 10^6 \text{ m}^3 \text{ day}^{-1}$

Depth to thermocline = 5.29 m (average depth)

Interval of stratification (May to mid-September) = 138 days

BOD loading = $934.27\ 10^6 \text{g} \cdot \text{yr}^{-1}$

Algal loading = $11800 \text{ mgCm}^{-2} \text{ day}^{-1}$

BOD concentration = $\dfrac{934.27 \times 10^6 \text{ g/yr}}{3.71 \times 10^7 \text{m}^3 \times 365 \text{ days/yr}} = 0.069 \text{ mg/l}$

Temperature = 10°C

Rates and Input Values

M	=	0.8	k_1	=	0.063 day^{-1}
S	=	2.67	k	=	0.0378 day^{-1}
P	=	$0.824 \text{ gC m}^{-2} \text{ day}^{-1}$	k_4	=	0.0019 day^{-1}
$\bar{D}$	=	5.29 m	DO_{sat}	=	11.3 mg/l
τ_w	=	21.4 day	t	=	138

The simplified model used to predict hypolimnion dissolved oxygen levels assumes that the only substantial dissolved oxygen sinks are water column and benthic deposit BOD (Section 5.5). Additionally, all sources of oxygen, photosynthesis, etc., are neglected in the hypolimnion after the onset of stratification. Thus, the procedure requires that pre-stratification levels of BOD and dissolved oxygen be estimated in order to compute the post-stratification rate of oxygen disappearance. The pre-stratification concentration of water column BOD is determined first. A simple mass balance leads to the following relationship, if steady state conditions are assumed:

$$C_{ss} = -\frac{k_a}{k_b}$$

where

C_{ss} = steady state concentration of BOD in water column, mg/l^{-1}
k_a = mean rate of BOD loading from all sources $g\ m^{-3}\ day^{-1}$
$k_b = -k_s - k_1 - \frac{1}{\tau_w}$

where

k_s = $V_s/\bar{Z}$ = mean rate of BOD settling out onto impoundment bottom, day^{-1}

k_1 = mean rate of decay of water column BOD, day^{-1}

Q = mean export flow rate, $m^3\ day^{-1}$

V = impoundment volume, m^3

V_s = settling velocity, $m\ day^{-1}$

$\bar{Z}$ = impoundment mean depth, m.

The BOD load to the impoundment originates in two principal sources: algal growth and tributary loads. The algal BOD loading rate is computed from the expression:

$$k_{a(algae)} = SMP/\bar{Z}$$

S = stoichiometric conversion from algal biomass as carbon to BOD = 2.67

M = proportion of algal biomass expressed as oxygen demand

P = algal primary production, $g\ m^{-2}$ day

Since the Chiaudani and Vighi curve (Figure V-26) gives the maximal algal production, a correction should be made for the actual epilimnion temperature. If the maximal rate occurs at 30°C and the productivity decreases by half for each 15°C decrease in temperature, the algal production can be corrected for temperature using the expression:

$$P_{(T)} = P_{(30)} \times 1.047^{(T-30^{o}C)}.$$

According to the data in Table 1, the epilimnion temperature during the month prior to stratification is approximately 13°C. Thus:

$$P_{(13^{o})} = (1.8)\ \mathrm{gC\ m^{-2}\ day^{-1}} \times 1.047^{(13^{o}C-30^{o}C)}$$

$$= 0.824\ \mathrm{gC\ m^{-2}\ day^{-1}}\ .$$

If M is assumed to be 0.8, then:

$$k_{a(algae)} = \frac{2.67 \times 0.8 \times 0.824\ \mathrm{gC\ m^{-2}\ day^{-1}}}{5.293\ \mathrm{m}}$$

$$= 0.333\ \mathrm{g\ m^{-3}\ day^{-1}}$$

The BOD load borne by tributaries is found by the expression:

$$k_a(trib) = \frac{\text{Mean Daily BOD from Tributaries (Table V-18)}}{\text{Impoundment Volume}}$$

$$= \frac{934.27 \times 10^{6}\ \mathrm{g\ yr^{-1}}}{3.71 \times 10^{7}\ \mathrm{m^{3}}} \times \frac{1\ \mathrm{yr}}{365\ \mathrm{days}}$$

$$= 0.069\ \mathrm{g\ m^{-3}\ day}$$

The total BOD load to Occoquan Reservoir is then:

$$k_a = k_a(algae) + k_a(trib)$$

$$= 0.33\ \mathrm{g\ m^{-3}\ day^{-1}} + 0.069\ \mathrm{g\ m^{-3}\ day^{-1}}$$

$$= 0.402\ \mathrm{g\ m^{-3}\ day^{-1}}$$

Before the water column BOD concentration can be computed, the constants comprising k_b must be evaluated. The first of these, k_s, requires knowledge of the settling velocities of BOD particles.

Ideally these would be determined by using values of the physical properties of the particles and the water in the settling velocity equation, (V-6). Because such data are lacking, a settling velocity of 0.2 m day^{-1} reported for detritus will be substituted. The reported values lie between 0 and 2 meters day^{-1}, with most values close to 0.2 m day^{-1} (Zison _et_ _al_., 1978). Then,

$$k_s = 0.2 \text{ m day}^{-1}/5.29 \text{ m} = .0378 \text{ day}^{-1}$$

The second constant comprising k_b is the first-order decay rate constant for water column BOD. Reported values of k_1 vary widely depending on the degree of waste treatement. Zison _et_ _al_. (1978) presents data for rivers, but contains only two values for k_1 in lakes and estuaries. Both are $k_1 = 0.2 \text{ day}^{-1}$. Camp (1968) reports values from 0.01 for slowly metabolized industrial wastes to 0.3 for raw sewage. Because there is considerable sewage discharge into the Occoquan Reservoir, k_1 may be assumed to be in the upper range of these values, between 0.1 and 0.3 or 0.15 day^{-1}. Like the algal production rate, k_1 must be corrected for the water temperature. In April, the mean water temperature is about 11°C.

Then:

$$k = 0.095 \text{ day}^{-1} \times 1.047^{(11^{\circ}\text{C}-20^{\circ}\text{C})}$$

$$= 0.063 \text{ day}^{-1}$$

Finally, k_b is evaluated as follows:

$$k_b = -0.0378 \text{ day}^{-1} - 0.063 \text{ day}^{-1} - \frac{1}{21.4 \text{ days}}$$

$$= -0.148 \text{ day}^{-1}$$

Next, k_a and k_b may be substituted into the following equation to obtain C_{ss}.

$$C_{ss} = -\frac{k_a}{k_b}$$

$$C_{ss} = \frac{0.402}{0.148} = 2.72 \text{ g m}^{-3}$$

Once the water column BOD concentration is known, the benthic BOD is computed from the expression:

$$L_{ss} = \frac{k_s \, C_{ss} \, \overline{D}}{k_4}$$

where

k_4 = mean rate of benthic BOD decay, day^{-1}.

Values for the benthic BOD decay rate constant span a greater range than those for water column BOD. Camp (1968), however, reports values of k_4 very near 0.003 day^{-1} for a range of benthic depth from 1.42 to 10.2 cm (Table V-10). Assuming this to be a good value, a temperature-corrected value of k_4 may be computed at an April hypolimnion temperature of 10^{o}C (Table V-17):

$$k_4 = 0.003 \text{ day}^{-1} \times 1.047^{(10-20)} = 0.0019 \text{ day}^{-1}$$

Then,

$$L_{ss} = \frac{0.0378 \text{ day}^{-1} \times 2.72 \text{ g m}^{-3} \times 5.29 \text{ m}}{0.0019 \text{ day}^{-1}}$$

$$= 286 \text{ g m}^{-2}$$

Prior to stratification the impoundment is assumed to be fully mixed and saturated with oxygen. During April, the hypolimnion temperature is 10^{o}C. Saturated water at this temperature contains 11.3 ppm oxygen (Table V-11).

Finally, the dissolved oxygen level in the hypolimnion may be predicted during the period of stratification. The applicable expressions are:

$$\Delta O_L = \overset{A}{(1.04)}\ [\overset{B}{(53.1)}\ \overset{C}{(0.231)} - (\overset{E}{1}/\overset{B}{53.1})]$$

$$\Delta O_L = 12.74$$

$$\Delta O_c = \overset{F}{(1.7)}\ \overset{E}{(1)} = 1.7$$

$$O_t = 11.3 - 12.74 - 1.7$$

Therefore the hypolimnion is depleted of oxygen at the end of the stratification period (138 days). By selecting different conditions for decay rates and for time of stratification a family of curves was generated that can be compared with actual observations (Figure V-39). As can be seen situations 3 and 4 (BOD decay of 0.3 later corrected for temperature and a total BOD loading of 0.36 or 0.57 g $\cdot$ m^{-3} day^{-1}) gave a reasonable fit of observed data at the deepest station (Occoquan Dam, 1973).

Interpretation of the dissolved oxygen-time data at High Dam in 1970 presented in Figure V-39 is complicated by the introduction of fresh oxygen after the onset of stratification. Although a direct comparison of oxygen depletion times is not possible, the rates of oxygen level follows curve 2 of Figure V-39 very closely, while during the second period of oxygen consumption the oxygen concentrations closely match those of curve 1. Since the reservoir is shallowest at High Dam and the substantially lower than average flow rate in 1970 resulted in strongly stratified conditions, the oxygen depletion rates in this case should be among the highest likely to be observed in the impoundment. Curve 1 represents the fastest decay rates predicted by the model. Thus, the observed oxygen consumption times should be greater than the lower limit predicted by the model in nearly all cases.

The above agreement of the observed with the predicted limits for the range of oxygen depletion times in Occoquan Reservoir implies that the typical or average time must also fall within the predicted range. Since it was for "average" conditions that the impoundment was modeled,

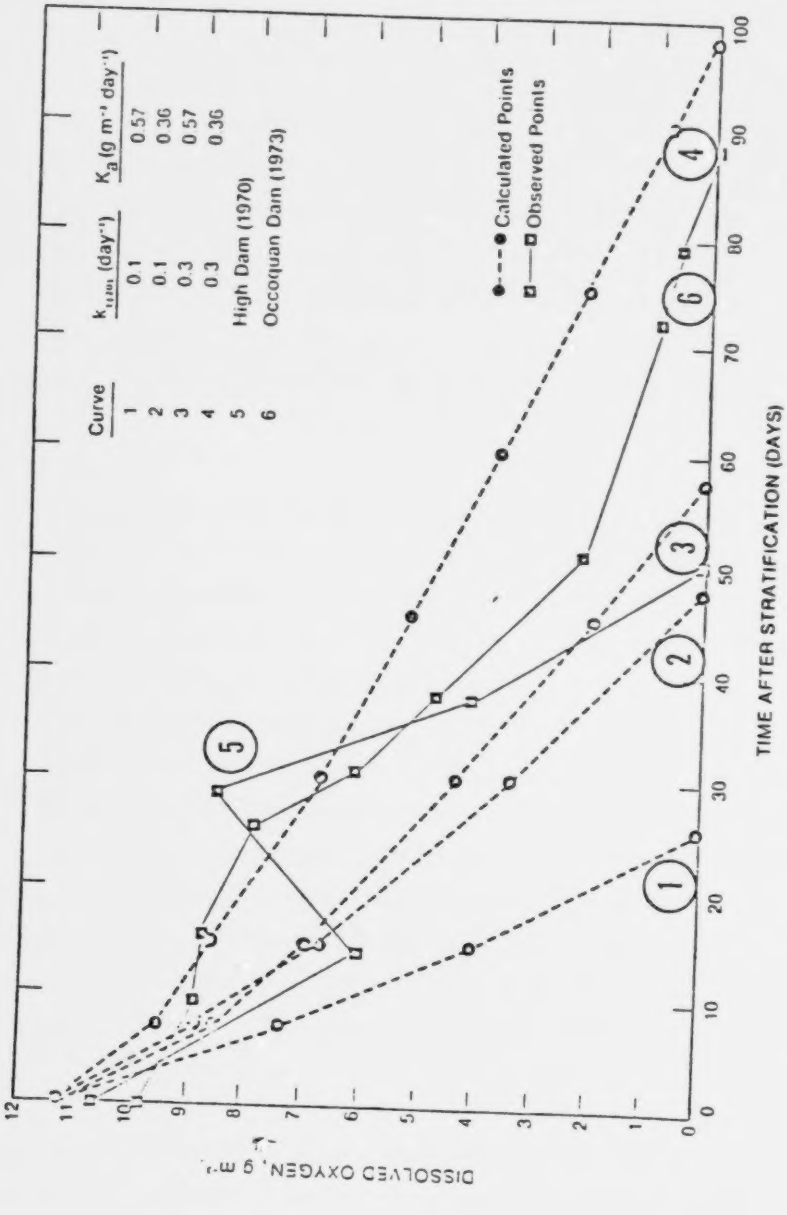


FIGURE V-39 DISSOLVED OXYGEN DEPLETION VERSUS TIME IN THE OCCOQUAN RESERVOIR

it may be concluded that the model does accurately describe the behavior of the Occoquan Reservoir.

5.7.6 Toxicants

It was not possible to obtain data on toxicants in Occoquan Reservoir. In order to provide a problem with some realism, published data on a priority pollutant in another reservoir were obtained. In Coralville Reservoir, Iowa, commercial fishing was banned in 1976 because of excessive accumulation of dieldrin residues in flesh of commercially important bottom feeding fish (Schnoor, 1981). The dieldrin arose from biodegraded aldrin, an insecticide in wide use along with dieldrin before cancellation of registration of both pesticides by USEPA in 1975.

After 1976 there was steady diminution of dieldrin in the waters, fish, and bottom sediments of Coralville Reservoir, until the late 1970's when dieldrin levels in fish flesh declined to less than 0.3 mg/kg (Food & Drug Administration guideline). In 1979, the fishing ban was rescinded.

Using the screening methods and data abstracted from Schnoor's paper, the potential dieldrin problem can be evaluated in Coralville Reservoir. Available and back-calculated data include the following values:

Reservoir	Dieldrin
τ_w = 14 days = 336 hrs	kow = 305000
$\bar{Z}$ = 8 feet = 2.4 m	koc = 35600
C_{in} = 0.05 μg/l dieldrin	solubility in fresh water ≅ 200 μg/l

OC = 0.05 (estimate)
So = 200 μg/l (estimate) = 200×10^{-6} kg/kg
P = 0.9 (estimate)

Assuming that conditions remained constant, the steady state concentration of dieldrin can be computed using the approach described in Section 5.6 as follows:

$$C = C_{in} / (1 + \tau_w \cdot k)$$

where

$$K = SED + B + k_v + k_p + k_h.$$

Evaluation of K depends on estimation of the separate rate constants. Information in Chapter 2 and in Callahan, et al. (1977) indicate that the biodegradation rate (B) in aquatic systems is extremely small. Similarly volatilization (k_v) and hydroloysis (k_h) are negligible processes affecting the fate of dieldrin. Photolysis (k_p) can be significant in some circumstances but the high turbidity in Coralville Reservoir indicates that minimal photolysis takes place. Consequently, $K \cong SED$. These assumptions are supported by Schnoor (1981).

Calculation of the sedimentation rate constant (SED) is as follows:

$$SED = a \times D \times K_p$$

$$K_p = 0.63 \times kow \times OC$$

$$= 0.63 \times 305000 \times 0.05$$

$$= 9610$$

$$D = P \times 50 \times \frac{1}{\tau_w}$$

$$D = 0.9 \times 200 \times 10^{-6} \times \frac{1}{336} = 5.36 \times 10^{-6} m^{-1}$$

$$a = 1/(1 + k_p S)$$

$$S = OC \times 50 = .05 \times 200 \times 10^{-6} = 1 \times 10^{-5}$$

$$a = 0.912 \times 5.36 \times 10^{-5} \times 9610$$

$$= 0.0047\ m^{-1}$$

The steady state concentration of dieldrin in Coralville Reservoir is estimated to be:

$$C = 0.05\ \mu g/l \quad (1 + (0.0047\ hr^{-1} \times 336\ hr))$$
$$C = 0.019\ \mu g/l$$

This value is much greater than the present fresh water quality criteria of 0.0023 dieldrin µg/l (Federal Register: 79318-79379. Nov. 28, 1980) and would indicate a serious potential problem in the reservoir that would require significant action and study.

Evaluation of bioconcentration supports this conclusion:

$$Y = BCF \times C$$

If the default estimate is used (Section 5.6.1.6):

$$\log BCF = 0.75 \log KOW - 0.23$$

$$= 3.88$$

$$BCF = 7642$$

$$Y = 7642 \times 0.019 = 145\ \mu g/kg \text{ fish flesh}$$

This value would be less than the FDA guideline. However, two published BCF values are available: 35600 from Chapter 2; 70000 from Schnoor (1981). These values produce much higher tissue burdens, both of which violate the FDA guideline:

$$Y = 35600 \times 0.019 = 676\ \mu g/kg$$

$$Y = 70000 \times 0.019 = 1330\ \mu g/kg$$

In 1979, it is estimated that CI = 0.01 (calculated from Schnoor, 1981). Therefore, assuming other conditions are constant:

$$C = 0.01/\ (1 + (.0047 \times 336))$$

$$= 0.0039\ \mu g/l$$

A value about double the water quality criterion. Flesh concentration would be (using BCF = 70000):

$$Y = 70000 \times 0.0039 = 270\ \mu g/kg$$

This value (0.27 μg/kg) would be less than the FDA guidelines of 0.3 μg/kg and support the conclusion to lift the fishing ban. Schnoor (1981) shows the following measured data that can be compared to the screening results:

	1970		1979	
	Water	Fish	Water	Fish
Screening	0.019	1300	0.04	270
Measured	0.015	1100	0.005	250

REFERENCES

Callahan, M., M. Slimak, N. Gabel, I. May, C. Fowler, R. Freed, P. Jennings, R. Durfee, F. Whitmore, B. Maestri, W. Mabey, B. Holt, C. Gould, 1979. Water-Related Environmental Fate of 129 Priority Pollutants, Volumes I, II. USEPA Report, EPA 440/4-79-029a,b. NTIS Reports: PB80 204373, PB80 204381. b.

Camp, T.R., 1968. Water and Its Impurities. Reinhold Book Corporation. New York.

Chen, C.W., and G.T. Orlob, 1973. Ecologic Study of Lake Koocanusa Libby Dam. Corps of Engineers, U.S. Army, Seattle District.

Chiaudani, G., and M. Vighi, 1974. "The N:P Ration and Tests with Selenastrum to Predict Eutrophication in Lakes", Water Research, 8:1063-1069.

Cowen, W.F. and G.F. Lee, 1976. Phosphorus Availability in Particulate Materials Transported by Urban Runoff. J. Wat. Pol. Control Fed. 48:580-591.

Dean, J.D., F.J.M. Hudson, and W.B. Mills, 1979. Cheasapeake- Sandusky: Non-designated 208 Screening Methodology Demonstration. Midwest Research Institute, Kansas City, MO. USEPA Respt. for Env. Res. Lab., Athens, GA. In Press.

Dillon, P., 1974. "A Manual for Calculating the Capacity of a Lake for Development", Ontario Ministry of the Environment.

Dillon, P. and F. Rigler, 1975. Journal Fisheries Research Board of Canada, Vol. 32, No. 9.

Dorich, R.A., D.W. Nelson and L.E. Sommers, 1980. Algal Availability of Sediment Phosphorus in Drainage Water of the Black Creek Watershed. J. Environ. Qual. 9:557-563.

Drury, D.D., D.B. Porcella, and R.A. Gearheart, 1975. ThE effects of Artificial Destratification on the Water Quality and Microbial Populations of Hyrum Reservoir. PRJEW011-1. Utah State University, Logan, UT.

Grizzard, T.J., J.P. Hartigan, C.W. Randall, J.I. Kim, A.S. Librach, and M. Derewianka, 1977. Characterizing "Runoff Pollution-Land Use". Presented at MSDGC-AMSA Workshop, Chicago. VPISU, Blacksburg, VA 24061. 66 p.

Hudson, R.J.M., and D.B. Porcella, 1980. Selected Organic Consent Decre Chemicals: Addendum to Water Quality Assessment, A Screening Method For Non-designated 208 areas. USEPA Rept for Env. Res. Lab, Athens, GA, In Press.

Hutchinson, G.E., 1957. A Treatise on Limnology. Vol. I. John Wiley & Sons, Inc. New York. 1015 p.

Hydrologic Engineering Center (HEC), Corps of Engineers, 1974. Water Quality for River-Reservoir Systems. U.S. Army Corp of Engineers.

Jones, J.R. and R.W. Bachmann, 1976. Prediction of Phosphorus and Chlorophyll Levels in Lakes. JWPCF 48:2176-2182.

Larsen, D.P. and H.T. Mercier, 1976. Phosphorus Retention Capacity of Lakes. J. Fish. Res. Board Can. 331731-1750.:

Likens, G.E. et al., 1977. Biogeochemistry of a Forested Ecosystem. Springer-Verlog, New York. 146 p.

Linsley, R.K., M.A. Kohler, and J.H. Paulhus, 1958. Hydrology for Engineers. McGraw-Hill Book Company, New York.

Lorenzen, M.W. et al., 1976. "Long-Term Phosphorus Model for Lakes: Application to Lake Washington:, in Modeling Biochemical Processes in Aquatic Ecosystems. Ann Arbor Science Publishers. pp 75-91.

Lorenzen, M.W., 1978. "Phosphorus Models and Eutrophication", in Press.

Lorenzen, M.W., and A. Fast, 1976. A guide to Aeration/Circulation Techniques for Lake Management: For U.S. Environmental Protection Agency, Corvallis, Oregon.

Lund, J., 1971. Water Treatment and Examination, Vol. 19. pp 332-358.

Marsh, P.S., 1975. Siltation Rates and Life Expectancies of Small Headwater Reservoirs in Montana. Report No. 65, Montana University Joint Water Resources Research Center.

Rast, W. and G.F. Lee., 1978. Summary Analysis of the North American (US Portion) OECD Eutrophication Project. EPA-600/3-78-008. USEPA, Corvallis, Oregon 93770. 454 p.

Sakamoto, M., 1966. Archives of Hydrobiology, Vol. 62. pp 1-28.

Schnoor, J.L., 1981. Fate and Transport of Dieldrin in Coralville Reservoir: Residues in Fish and Water Following a Pesticide Ban. Science. 211:804-842.

Stumm, W., and J.J. Morgan, 1970. Aquatic Chemistry. Wiley-Interscience, New York.

Vollenweider, R.A., 1976. Advances in defining critical loading levels for Phpsphorus in Lake Eutrophication. Mem. Ist. Ital. Idrobiol. 33: 53-83.

U.S. Department of Commerce, 1974. Climatic Atlas of the United States, U.S. Department of Commerce, Environmental Sciences Services Administration Environmental Data Service, Washington, D.C.

U.S. Environmental Protection Agency, 1975. National Water Quality Inventory. Report to Congress, EPA-440/9-75-014.

Zison, S.W., W.B. Mills, D. Deimer, C.W. Chen, 1978. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. EPA-600/3-78-105. USEPA, Athens, GA 30605. 316 p.

GLOSSARY OF TERMS

Significant variables are shown with typical units. Units must be compatible or use conversion factors (Chapter 1). Note that some symbols are used for more than one term.

A	Lake surface area, m^2 - sediment area, m^2
a	Fraction of pollutant in solution = $1/(1+(K_p \times S))$, unitless
B	Biodegradation rate, hr^{-1}
B(T)	Biodegradation rate, corrected for temperature T, hr^{-1}
BCF	Bioconcentration factor, unitless
Bo	Initial microbial biodegradation rate, uncorrected for temperature or nutrient concentration, hr^{-1}
C	Reservoir concentration at time, t, mgl^{-1}
C_o	Initial concentration, mgl^{-1}
C_p	Concentration of phosphorus, μgPl^{-1}
C_s	Total exchangeable phosphorus concentration in the sediments, $g\ m^{-3}$
C_s	Toxicant concentration sorbed on sediment, $mg\ l^{-1}$
C_t	Concentration of BOD at time t, $mg\ l^{-1}$
C_w	Concentration in water phase, $mg\ l^{-1}$
C_w	Steady-state water column phosphorus concentration, $mg\ l^{-1}$, $g\ m^{-3}$
C_{in}	Steady state influent concentration, mg/l
C_{ss}	Steady-state water column BOD, $g\ m^{-3}$
C_{wt}	Weight concentration
C_{vol}	Volumetric concentration
D	Depth, m
D	Discharge channel depth, ft
D	Sedimentation rate constant = $P \times S \times Q/V$, $mg\ l^{-1}day^{-1}$
D	Dilution rate, day^{-1}
D'	Flowing layer depth, ft
D"	Inflow channel depth, ft
$\bar{D}$	Mean depth, m
$\bar{D}$	Depth to thermocline, m
D_h	Mean hypolimnion depth, m
D_i	Depth at the ith cross-section, m
Do	Diffusivity of oxygen in water ($2.1 \times 10^{-9}\ m^2\ sec^{-1}$, 20^oC)

D_p	Weight density of a particle, lb ft^{-3}
D_w	Weight density of water, lb ft^{-3}, g cm^{-3}
D_w	Pollutant diffusivity in water, m^2 sec^{-1}
d	Number of days per time period, days
d	Particle diameter, cm
f	1 + (τ_w x K), unitless
g	Acceleration due to gravity, 32.2 ft sec^{-2}
I_{SD}	Intensity of light at Secchi depth, relative units
I_o	Initial intensity of light at surface, relative units
K	Pollutant removal rate, = SED + B + k_v + k_p + k_h, hr^{-1}
K	Net rate of phosphorus removal, hr^{-1}
K_1	Specific rate of phosphorus transfer to the sediments, m yr^{-1}
K_2	Specific rate of phosphorus transfer from the sediments, m yr^{-1}
K_3	Fraction of total phosphorus input to sediment that is available for the exchange process, unitless
K_a	Reaeration rate, hr^{-1}
Ka_1	Reaeration coefficient, m hr^{-1}
K_p	Distribution coefficient between organic sediment and water, unitless
K_1	First order decay rate for water column BOD at 20°C, day^{-1}
K_4	Benthic BOD decay rate at 20°C, day^{-1}
K_a	Mean rate of BOD loading from all sources, g $m^{-3}day^{-1}$
K_a (algae)	Algal contribution to BOD loading rate, g $m^{-3}day^{-1}$
K_a (trib)	Tributary or point source contribution to BOD loading rate, g $m^{-3}day^{-1}$
K_b	$= -K_s - K_1 - (1/\tau_w)$, day^{-1}
k_e	Extinction coefficient, m^{-1}
k_h	Hydrolysis rate, hr^{-1}
k_p	Photolysis rate, hr^{-1}
k_r	Photolysis rate constant uncorrected for depth and turbidity of the lake, m^{-1}
k_s	Mean rate of BOD settling out onto the impoundment bottom, day^{-1}
k_v	Volatilization rate, hr^{-1}

koc	Organic carbon based partition coefficient, unitless
kow	Octanol-water coefficient, unitless
L	Areal BOD load, gm^{-2}
L_p	Phosphorus loading, $g\ m^{-2}yr^{-1}$
L_{ss}	Steady-state benthic BOD load, $g\ m^{-2}$
M	Total annual phosphorus loading, $g\ yr^{-1}$
M	Proportion of algal biomass expressed as an oxygen demand (unitless)
MW	Molecular weight, $g\ mole^{-1}$
OC	Sediment organic carbon fraction, unitless
ΔO_c	Dissolved oxygen decrease due to hypolimnion BOD, $mg\ l^{-1}$
ΔO_L	Dissolved oxygen decrease due to benthic demand, $mg\ l^{-1}$
O_o	Dissolved oxygen at time t = 0, $mg\ l^{-1}$
O_t	Dissolved oxygen at time t, $mg\ l^{-1}$
p	Sediment trapping efficiency, unitless $1 \geq P \geq 0$
P	Primary productivity rate, g Carbon m^{-2} day^{-1}
P	Total phosphorus in the water column, $mg\ m^{-3}$
PI	Influent phosphorus, $mg\ l^{-1}$
QI	Mean annual inflow, $m^3\ yr^{-1}$
Q	Mean Annual outflow, $m^3\ yr^{-1}$
q_s	Hydraulic loading $(\bar{Z}/\tau_w)$, $m\ yr^{-1}$
R	Reynolds number, unitless
r	Radius, ft
S	Stoichiometric conversion from algal biomass as carbon to BOD, 2.67, unitless
S	Input suspended organic sediment = OC x So, $mg\ l^{-1}$
S_i	Mass of sediment in inflow per unit time, $mg\ l^{-1}$
S_o	Input of suspended sediment, $mg\ l^{-1}$
S_t	Sediment trapped, metric tons yr^{-1}
SD	Secchi depth, m
SDR	Sediment delivery ratio, unitless
SED	Sorption and sedimentation rate (toxicant at equilibrium with sediments), hr^{-1}
T	Temperature, degrees centigrade

V	Lake or impoundment volume, m^3
V_H	Hypolimnion volume, l
V_s	Sediment volume, m^3
V_{max}	Terminal velocity of a spherical particle, ft sec^{-1}
W	Wind speed, m sec^{-1}
Y	Tissue concentration of pollutant, μg kg^{-1} fish flesh
y	number of years
Z	depth, m
$\bar{Z}$	mean depth, m
μ	Absolute viscosity of water, lb sec ft^{-2}, g sec cm^{-2}
ρ_p	Mass density of a particle, slugs ft^{-3}
ρ_w	Mass density of water, slugs ft^{-3}
τ_w	Mean hydraulic residence time (V/Q),days

Chapter 6

ESTUARIES

6.1 INTRODUCTION

6.1.1 General

Estuaries are of primary social, economic, and ecologic importance to America. Forty-three of 110 of the Department of Commerce's Standard Metropolitan Statistical Areas are on estuaries (DeFalco, 1967). Estuaries are the terminal or transfer point for essentially all waterborne national and international commerce in this country, and biologically are more productive on a mass per unit area basis than any other type of water body. Essentially all conservative wastes and much of the nonconservative wastes discharged into any inland stream in America eventually pass into an estuary. Yet these coastal formations on which there is such a demand for services are less stable geologically than any other formation found on the continent (Schubel, 1971). Sedimentation processes, for example, are filling, destroying, or at least altering all estuaries. While this process is always rapid in a geological sense, the actual length of time required for complete estuarine sedimentation is a function primarily of the stability of the sea level, the rate of sediment influx, and the intra-estuarine circulation pattern (Schubel, 1971). The instability, variation, and complexity of estuaries make water quality assessment and prediction especially difficult, yet the demands placed on estuaries require a most active water quality management program.

This chapter will describe a systematic approach which may be used to provide estuarine water quality assessment and prediction. Its purpose is two-fold. First, the planner will be provided the capability of making elementary assessments of current estuarine water quality. Second, methodologies are presented by which the planner can evaluate changes in water quality which might result from future changes in waste loading.

Chapter 3 provided methodologies for assessing the waste load directly entering an estuary. Chapter 4 provided methodologies which can be used to assess the water quality of a river or stream as it enters an estuary. The output of these chapters will provide information about present and projected estuarine water quality which can be used to identify regions having greatest water quality problems, water quality parameters of special concern, and areas for which subsequent computer study is necessary. Methods presented below comprise a screening tool which may be used by the planner to focus attention on critical spatial regions and water quality parameters. These can then be fully assessed using computer models or other techniques, as desired.

6.1.2 Estuarine Definition

It is difficult to provide a concise, comprehensive definition of an estuary. The basic elements included in most current definitions are that an estuary is:

a. a semi-enclosed coastal body of water,

b. freely connected to the open sea,

c. influenced by tidal action, and

d. a water body in which sea water is measurably diluted with fresh water derived from land drainage (Pritchard, 1967; Pritchard and Schubel, 1971).

The seaward end of an estuary is established by the requirement that an estuary be semi-enclosed. Because this boundary is normally defined by physical land features, it can be specifically identified. The landward boundary is not as easily defined, however. Generally tidal influence in a river system extends further inland than does salt intrusion. Thus the estuary is limited by the requirement that both salt and fresh water be measurably present. Accordingly, the landward boundary may be defined as the furthest measurable inland penetration of sea salts. The location of this inland boundary will vary substantially from season to season as a function of stream flows and stream velocities and may be many miles upstream from the estuarine mouth (e.g. approximately 40 miles upstream on the Potomac River, 27 miles on the James River, and approximately 16 miles upstream for the small Alsea Estuary in Oregon) (Pritchard, 1971). This definition also separates estuaries from coastal bays (embayments) by the requirement for a fresh water inflow and measurable sea water dilution.

6.1.3 Types of Estuaries

While the above definition provides adequate criteria for segregating estuaries from other major types of water bodies, it does not provide a means to separate the various types of estuaries from one another. The variations in estuarine circulation patterns and resulting variations in pollutant dispersion from estuary to estuary make classification a necessary part of any water quality assessment. Two basic estuarine classification systems have been used in recent years to accomplish estuarine subclass separation: a topographical system and a physical processes system (Dyer, 1973, Chapter 2 or Ippen, 1966, Chapter 10).

6.1.3.1 Topographical Classification

Under a topographical system, estuaries are divided into four subclasses. These are briefly described below.

a. Drowned River Valley (Coastal Plain Estuary). These estuaries are the result of a recent (within the last 10,000 years) sea level rise which has kept ahead of sedimentation processes at a river's mouth. Such estuaries are, quite literally, rivers whose lower basins have been drowned by the rising oceans. Coastal plain estuaries are characteristically broad, relatively shallow estuaries (rarely over 30 m deep) with extensive layers of recent sediment.

b. Fjord-like Estuaries. These estuaries are usually glacially formed and are extremely deep (up to 800 m) with shallow sills at the estuarine mouth. Fjord-like estuaries are restricted to high latitude mountainous regions and are not found in the United States outside of Alaska and Puget Sound in the state of Washington.

c. Bar-built Estuaries. When offshore barrier sand islands build above sea level and form a chain between headlands broken by one or more inlets, a bar-built estuary is formed. These estuaries are characteristically very shallow, elongated, parallel to the coast, and frequently are fed by more than one river system. As a result bar-built estuaries are usually very complex hydrodynamically. A number of examples of bar-built estuaries can be found along the southeast coast of the United States.

d. Tectonic Process Estuaries. Tectonic estuaries exist as the result of major tectonic events (movement of tectonic plates with associated faulting or subsidence and coastal volcanic activity). San Francisco Bay is a good example of an American estuary of this type.

Based on this topographic classification system, the vast majority of American estuaries fall into the drowned river class. As a result, this system is not functional for categorization of American estuaries. The classification system described below is based on physical processes and is more useful. Further, the parameters used in physical classification are directly applicable to estuarine pollution analysis. Consequently, a physical parameter classification system will be used for the water quality assessment approach to be presented.

6.1.3.2 Physical Process Classification

Physical process classification systems are generally based on the velocity and salinity patterns in an estuary. Using these two parameters, estuaries can be divided into three classes, each of which is of potential importance to planners concerned with American coastal plain estuaries. The classes are: stratified, partially mixed, and well mixed.

The general behavior of salinity and velocity regimes in the three types of estuaries has been described by a number of researchers (Glenne, 1967, Duxbury, 1970, Pritchard, 1960, and Dyer, 1973, among others) and is summarized below.

a. Stratified (Salt Wedge) Estuary. In this type of estuary, large fresh water inflows ride over a salt water layer which intrudes landward along the estuary bottom. Generally there is a continuous inland flow in the salt water layer as some of this salt water is entrained into the upper seaward-moving fresh water flow. Tidal action is not sufficient to mix the separate layers. Salinity (S) and Velocity (U) profiles and a longitudinal schematic of this flow pattern are shown in Figure VI-1. The Mississippi River Estuary is usually a salt wedge estuary.

b. Well Mixed. In a well mixed estuary, the tidal flow (or the tidal prism*) is much greater than the river outflow. Tidal mixing forces create a vertically well mixed water column with flow reversing from ebb to flood at all depths. Typical salinity and velocity profiles and a longitudinal flow schematic for a well mixed estuary are shown in Figure VI-2. As examples, the Delaware and Raritan River estuaries are both normally well mixed.

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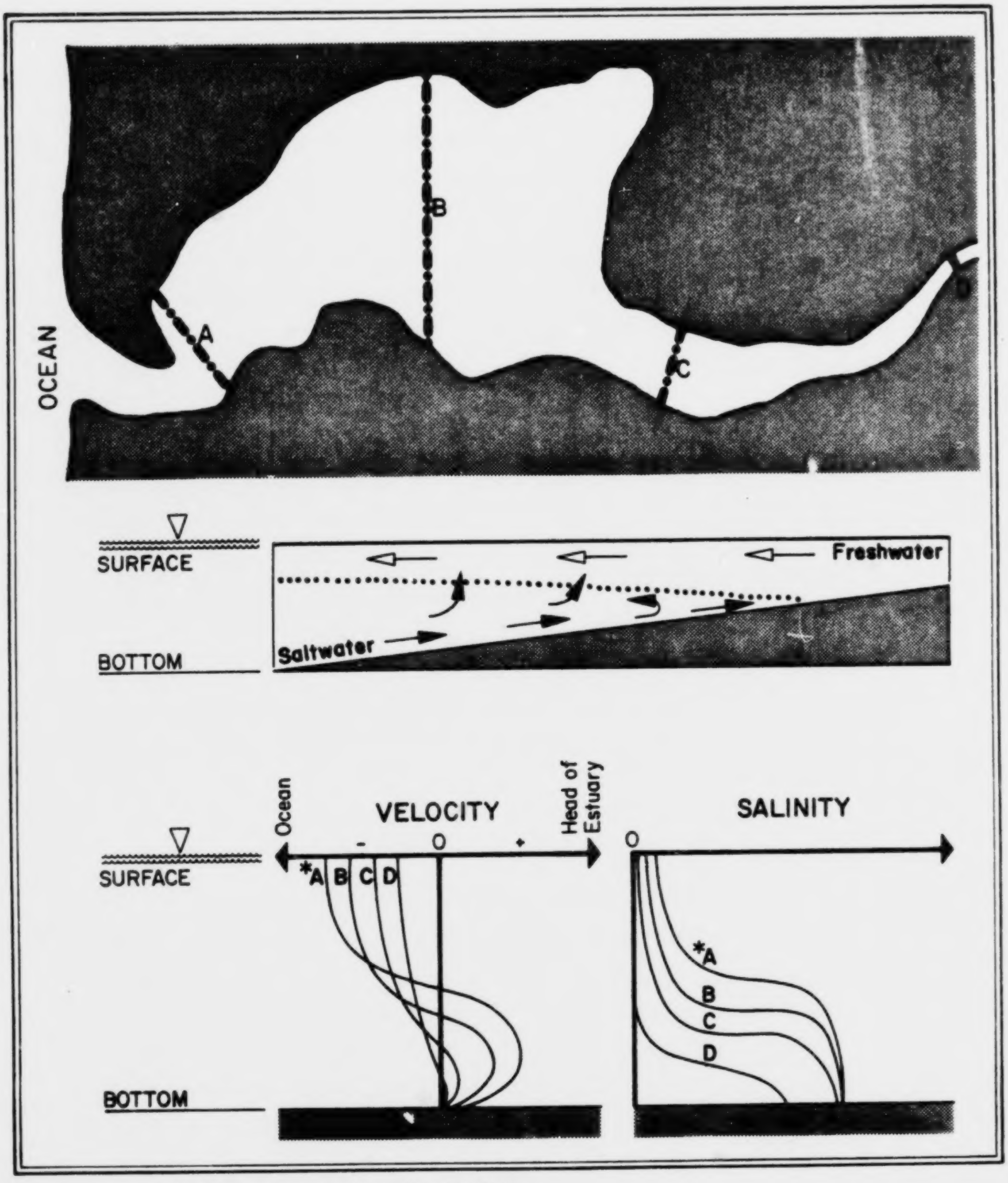
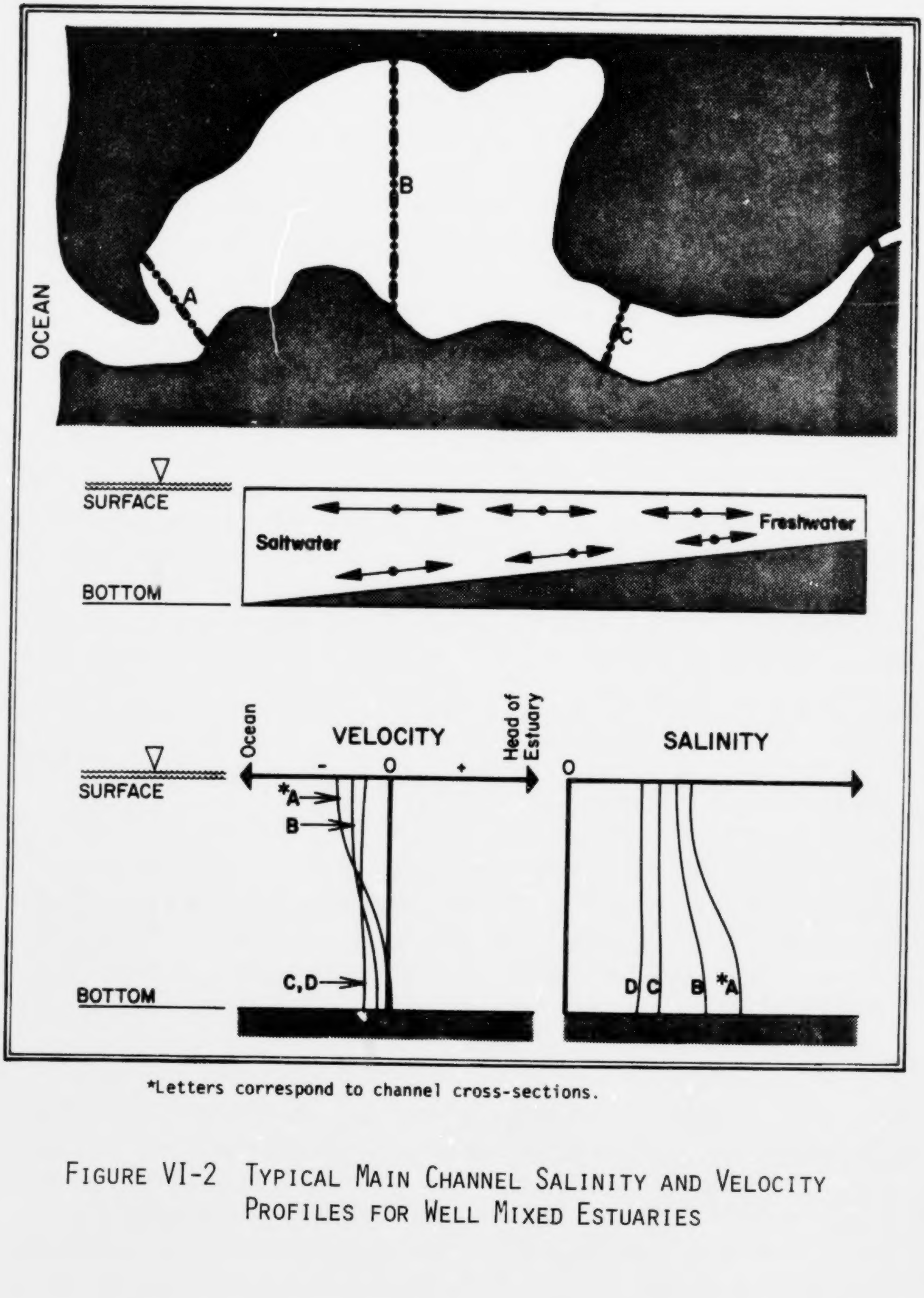
*The tidal prism is that volume of water which enters an estuary during an incoming (flood) tide and equals high tide estuarine volume minus low tide volume.



*Letters correspond to cross sections

FIGURE VI-1 TYPICAL MAIN CHANNEL SALINITY AND VELOCITY FOR STRATIFIED ESTUARIES



*Letters correspond to channel cross-sections.

FIGURE VI-2 TYPICAL MAIN CHANNEL SALINITY AND VELOCITY PROFILES FOR WELL MIXED ESTUARIES

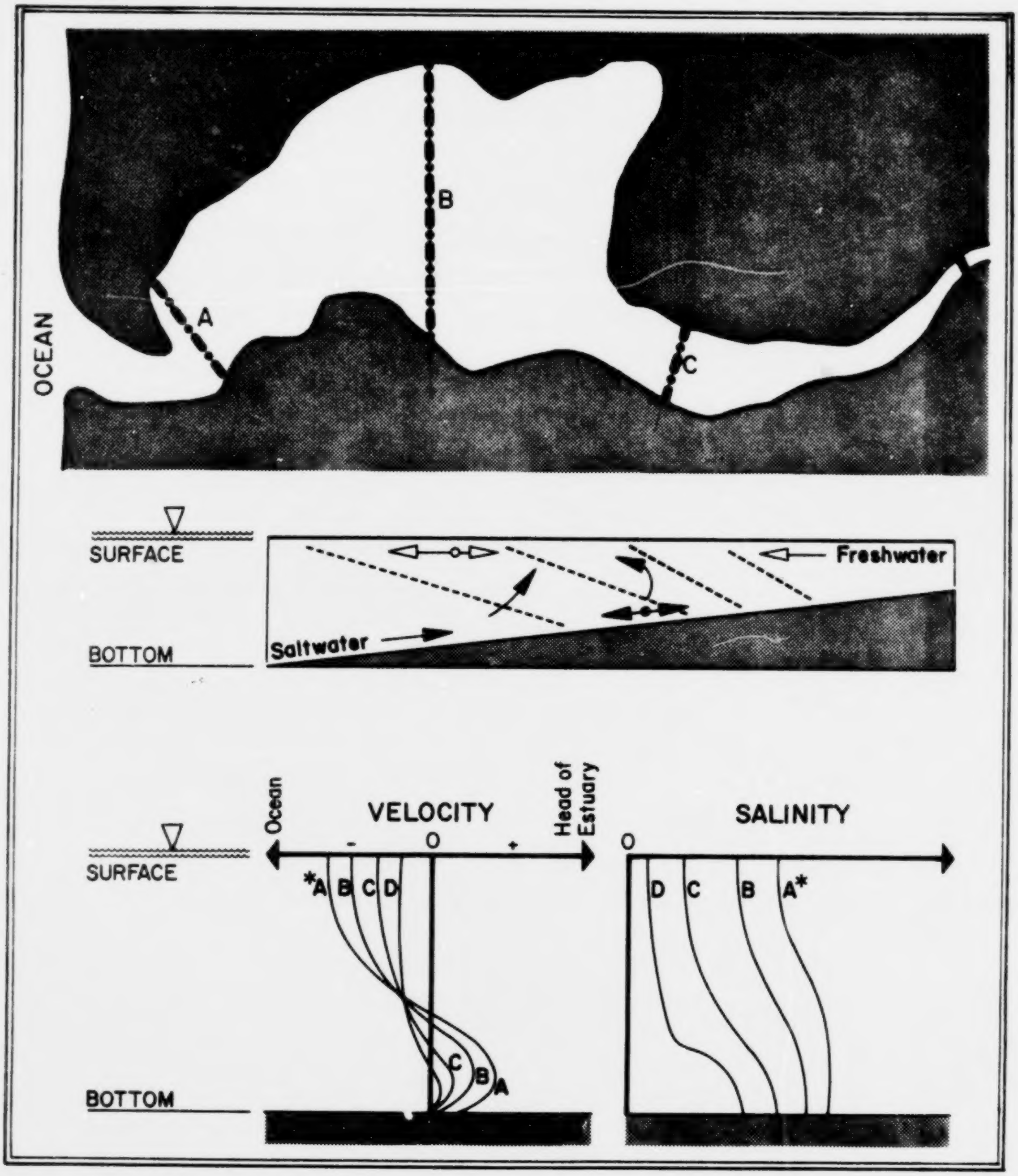
c. Partially Mixed. Partially mixed estuaries lie between stratified and well mixed in terms of flow and stratification characteristics. Tide-related flows in such estuaries are substantially greater than river flows. Significant salinity gradients exist as in fully stratified estuaries, but are much less steep. While velocity at all depths normally reverses with ebb and flood tide stages, it is possible for net inland flow to be maintained in the lowest layers. Typical salinity and velocity profiles and a longitudinal schematic flow diagram are shown in Figure VI-3. There are many partially mixed coastal plain estuaries in the United States; the lower James River Estuary is typical.

Classification primarily depends on the river discharge at the time of classification. Large river flows result in more stratified estuaries while low flow conditions in the same estuaries can lead to full mixing. Thus the classification of any single estuary is likely to vary from season to season as river flows vary. As examples, many west coast estuaries are partially mixed in winter when river flows are high and are well mixed in summer when river flows are very low.

6.1.4 Pollutant Flow in an Estuary

The importance of understanding the basic types of estuarine systems may be appreciated by briefly reviewing the general advective movements of a pollutant released into each of the three types of estuaries (summarized from Pritchard, 1960). The associated spatial and temporal variability of pollutant levels have water system management as well as water quality implications.

If a pollutant flow of density greater than the receiving water column is introduced into a salt wedge type estuary, the pollutant tends to sink into the bottom salt water layer and a portion can be advectively carried inland toward the head of the estuary. Frictionally induced vertical entrainment of the pollutant into the surface water flow is slow, residence time of the pollutant is high, and the time required to flush the pollutant



*Letters denote channel cross-sections

Figure VI-3 Typical Main Channel Salinity and Velocity Profiles for Partially Mixed Estuaries

from the estuary is also high. Some pollutants which are sufficiently dense and stable remain in or settle to the bottom layer of water, and are not transported out of a salt wedge estuary. Such constituents build up in the estuarine sediment layer.

Conversely, if a pollutant of lower density than the receiving water column is introduced into a salt wedge estuary, it remains in the surface layer and is readily flushed from the system. This is the case because seaward flows strongly predominate in this layer.

At the opposite end of the estuary classification scale, a pollutant introduced into a well mixed estuary is advectively transported in a manner independent of the pollutant's density. Tidal forces cause turbulent vertical and lateral mixing. The pollutant is carried back and forth with the oscillatory motion of the tides and is slowly carried seaward with the net flow.

Pollutants introduced into partially mixed estuaries are dispersed in a manner intermediate between the transport patterns exhibited in well mixed and stratified estuaries. Pollutant transport is density dependent but nevertheless involves considerable vertical mixing. Eventual flushing of the pollutant from an estuary in this case depends on the relative magnitudes of the net river outflow and the tidal seawater inflow.

6.1.5 Estuarine Complexity and Major Forces

Before outlining the complexities of estuarine systems, a brief review of the nomenclature used in this chapter will be helpful. This information is shown in Figure VI-4. This figure shows top, side, and cross sectional views of an estuary and indicates the basic estuarine dimensions. Additionally, the relationship between tidal elevation (or tidal stage) and surface water velocity is shown in the upper right quadrant of Figure VI-4.

The complexities of estuarine hydrodynamics are evident from even the brief qualitative descriptions presented above. Many variations in flow pattern and many of the forces acting on an estuarine water column have been

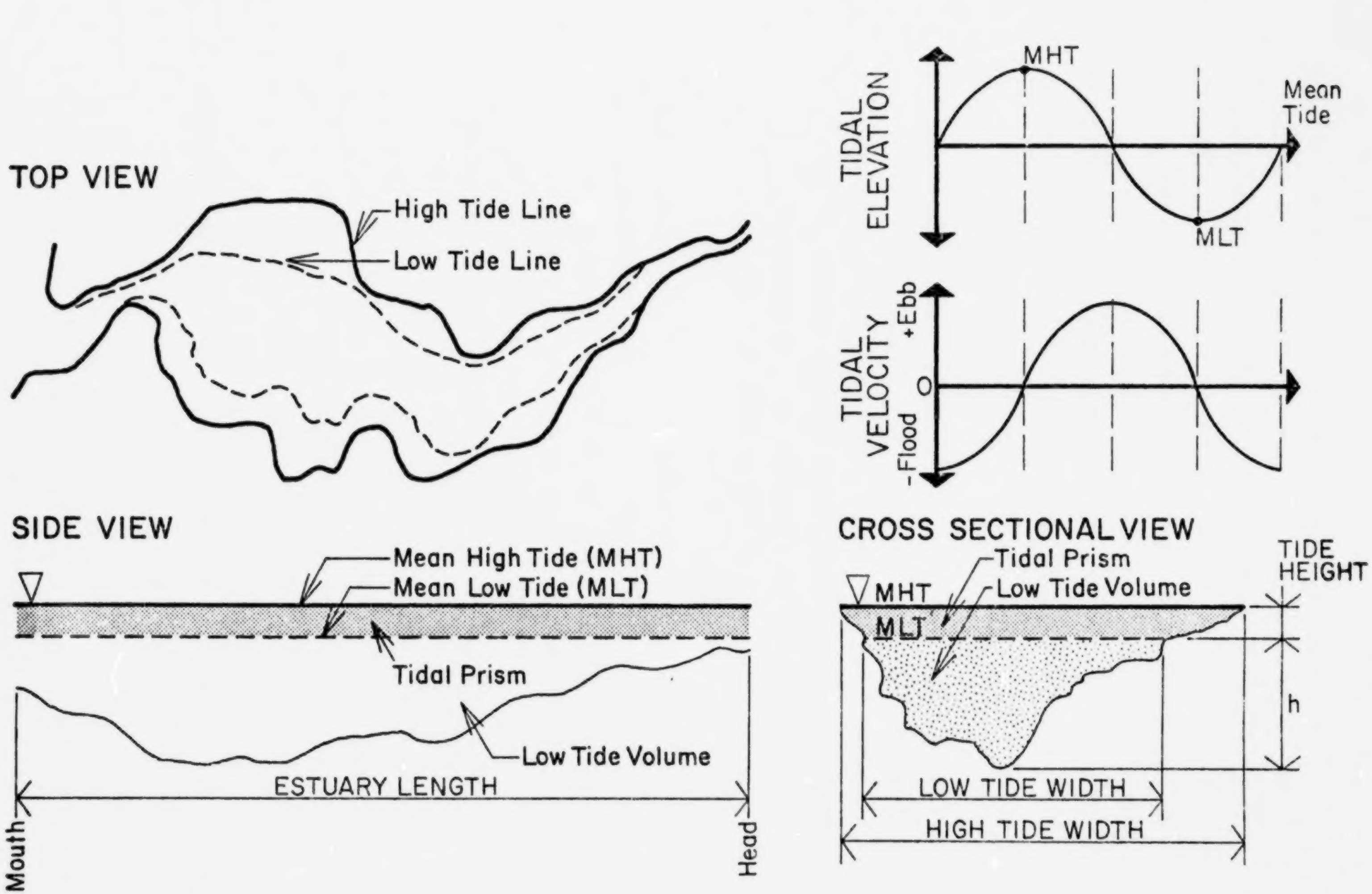


FIGURE VI-4 ESTUARINE DIMENSIONAL DEFINITION

omitted in order to permit a verbal description of the normally predominant phenomena, and it should be understood that the descriptions do not fully account for the complexities of estuarine motion. Estuarine circulation may be conceived as a three-dimensional flow field with variations possible in salinity and velocity along the longitudinal, the vertical, and the lateral axes. As a result of this complexity, and because an estuary is a transitional zone between fresh water and marine systems, great variations in a number of major water quality and physical parameters are possible. For example:

a. pH. Typical ocean pH is 7.8 to 8.4. Typically, rivers are slightly acidic ($pH<7$). Thus the pH can change from slightly acidic to basic across an estuary with resulting major changes in chemical characteristics of dissolved and suspended constituents. pH variations from 6.8 to 9.25 across an estuary have been recorded (Perkins, 1974, p. 29).

b. Salinity. Over the length of an estuary, salinity varies from fresh water levels (typically less than 1 ppt) to oceanic salinity levels (usually 32 ppt to 34 ppt)*. Moreover salinity at any given location in an estuary may vary substantially over one tidal cycle and over the depth of the water column at any single point in time. Salinity variations are especially significant in estuarine calculations for a variety of reasons. First, salinity distribution can be used to predict the distribution of pollutants; second, salinity is a prime determinant of water density; and third, variations in salinity affect other major water quality parameters. For example, the saturated dissolved oxygen concentration normally diminishes by 2 mg/l as salinity increases from 0 to 35 ppt.

c. River Flow. River flow is a major determinant of estuarine circulation and flushing characteristics. Instantaneous flow rates for some western rivers vary by orders of magnitude from winter high flow to summer low flow periods (Goodwin, et al., 1970). These differences in river flow result in major variations in estuarine water quality characteristics.

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*ppt represents parts per thousand by mass. Sometimes the symbol $^{o}/oo$ is used.

d. Time. Estuarine water quality parameters vary over several separate time scales. First, variations occur with each tidal cycle over a period of hours. Second, tidal cycles vary in mean amplitude from spring (maximum amplitude) to neap tides (minimum amplitude) every two weeks. This affects water quality since flushing characteristics are in part dependent on the tidal prism which is, in turn, dependent on tide stage. Third, there are seasonal variations in river flow, temperature and waste loadings.

The four factors just listed affecting the range and rate of variation of estuarine parameters pose part of the difficulty in analyzing estuarine water quality. In order to avoid large errors, both small time increments and small spatial increments must be used. This, in turn, necessitates a large number of individual calculations to fully analyze the variation of even a single parameter over the estuary and sometimes requires the use of a computer model.

Further complicating the analytical process is the large number of independent forces acting on the estuarine water column which should be considered. This group includes (from Harleman and Lee, 1969):

a. Ocean tides
b. Local wind stresses
c. Bottom roughness and bottom sediment types
d. Channel geometry
e. Coriolis forces*
f. Nearby coastal features and coastal processes

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*Coriolis forces reflect the effect of a rotating reference plane (the earth) on particle motion. The net effect is to cause a water flow to drift to one side as it propogates down a channel. The same effect tends to laterally segregate fresh water flows (moving from head to mouth) and salt water inflows (moving from mouth to head) in an estuary and in the northern hemisphere to create a counterclock-wise flow pattern with fresh water to the right (looking from the head of the estuary toward the mouth) flowing toward the sea and salt water on the left flowing toward the head of the estuary.

6.1.6 Methodology Summary

A variety of techniques are presented in this chapter to assess water quality in estuaries. Table VI-1 summarizes the techniques and indicates if they are applicable to one-dimensional (well-mixed) or two-dimensional (vertically stratified) estuaries. Many of the techniques can be applied to conventional or toxic pollutants. If decay rates for toxic pollutants are needed, Chapter 2 can be used.

It is redundant to describe in detail each method at this point in the chapter, because the procedures are presented later. As a general statement, however, most of the methods for prediction of water quality apply to continuous, steady-state discharges of pollutants. The discharges can be located anywhere within the estuary, from head to mouth. Multiple sources of pollutants can be analyzed by applying the method of superposition, which is illustrated subsequently.

Although no single sequence of calculations must be followed to use the methodology, Figure VI-5 shows a suggested procedure. It is often useful to begin by classifying the estuary by season to find out when it is well mixed and when it is stratified. If the estuary is never well mixed, then the tools listed in Table VI-1 pertaining to one-dimensional estuaries should not be used.

Users are cautioned that the methods in this chapter are of a simplified nature, and consequently there are errors inherent in the calculations. Additionally, inappropriate data can produce further systematic errors. Data used should be appropriate for the period being studied. For example, when salinity profiles are needed, they should correspond to steady flow periods close to the critical period being analyzed.

Even though the methods presented in the chapter are amenable to hand calculations, some methods are more difficult to apply than others. The fraction of freshwater and modified tidal prism methods are relatively easy to apply, while the advective-dispersion equations offer greater computational challenge. Since the advective-dispersion equations require numerous calculations, the user might find it advantageous to program the methods on a hand calculator (e.g. TI-59 or HP-41C).

TABLE VI-1

SUMMARY OF METHODOLOGY FOR ESTUARINE WATER QUALITY ASSESSMENT

Calculations	Methods	Type of Estuary Applicable*
Estuarine Classification	• Hansen and Rattray	one- or two-dimensional
	• Flow ratio	one- or two-dimensional
Flushing Time	• Fraction of freshwater	one-dimensional
	• Modified tidal prism	one-dimensional
Pollutant Distribution	• Fraction of freshwater (conservative pollutants)[†]	one-dimensional
	• Modified tidal prism (conservative or first-order decay pollutants)[†]	one-dimensional
	• Dispersion-advection equations (conservative, first-order decay pollutants,[†] and dissolved oxygen)	one-dimensional
	• Pritchard's Box Model (conservative pollutants)[†]	two-dimensional
	• Initial dilution	one- or two-dimensional
	• Pollutant concentration at completion of initial dilution (conservative pollutants,[†] pH, dissolved oxygen)	one- or two-dimensional
	• Farfield distribution (conservative and first-order pollutants,[†] and dissolved oxygen)	two-dimensional
Thermal Pollution	• ΔT of water passing through condenser	not applicable
	• Maximum discharge temperature	not applicable
	• Thermal block criterion	one- or two-dimensional
	• Surface area criterion	one- or two-dimensional
	• Surface temperature criterion	one- or two-dimensional
Turbidity	• Turbidity at completion of initial dilution	one- or two-dimensional
	• Suspended solids at the completion of initial dilution	one- or two-dimensional
	• Light attenuation and turbidity relationship	one- or two-dimensional
	• Secchi disk and turbidity relationship	one- or two-dimensional
Sedimentation	• Description of sediment movement	one- or two-dimensional
	• Settling velocity determination	one- or two-dimensional
	• Null zone calculations	two-dimensional

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*One dimensional means a vertically well mixed system. A two dimensional estuary is vertically stratified.

[†] These methods apply to either conventional or toxic pollutants.

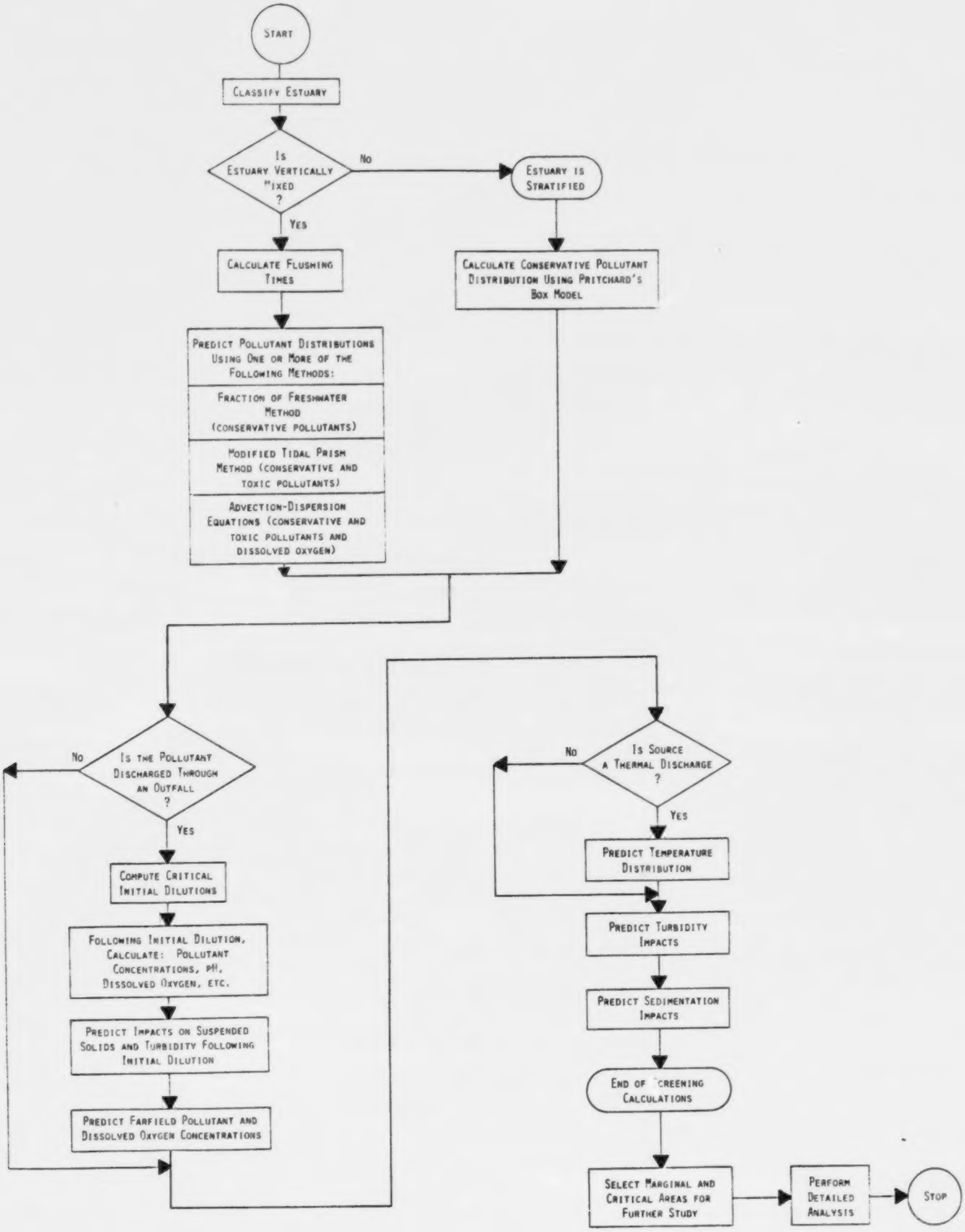

START
CLASSIFY ESTUARY
IS ESTUARY VERTICALLY MIXED ?
NO
YES
ESTUARY IS STRATIFIED
CALCULATE FLUSHING TIMES
CALCULATE CONSERVATIVE POLLUTANT DISTRIBUTION USING PRITCHARD'S BOX MODEL
PREDICT POLLUTANT DISTRIBUTIONS USING ONE OR MORE OF THE FOLLOWING METHODS:
FRACTION OF FRESHWATER METHOD (CONSERVATIVE POLLUTANTS)
MODIFIED TIDAL PRISM METHOD (CONSERVATIVE AND TOXIC POLLUTANTS)
ADVECTION-DISPERSION EQUATIONS (CONSERVATIVE AND TOXIC POLLUTANTS AND DISSOLVED OXYGEN)
IS THE POLLUTANT DISCHARGED THROUGH AN OUTFALL ?
NO
YES
COMPUTE CRITICAL INITIAL DILUTIONS
FOLLOWING INITIAL DILUTION, CALCULATE: POLLUTANT CONCENTRATIONS, PH, DISSOLVED OXYGEN, ETC.
PREDICT IMPACTS ON SUSPENDED SOLIDS AND TURBIDITY FOLLOWING INITIAL DILUTION
PREDICT FARFIELD POLLUTANT AND DISSOLVED OXYGEN CONCENTRATIONS
IS SOURCE A THERMAL DISCHARGE ?
NO
YES
PREDICT TEMPERATURE DISTRIBUTION
PREDICT TURBIDITY IMPACTS
PREDICT SEDIMENTATION IMPACTS
END OF SCREENING CALCULATIONS
SELECT MARGINAL AND CRITICAL AREAS FOR FURTHER STUDY
PERFORM DETAILED ANALYSIS
STOP

FIGURE VI-5 SUGGESTED PROCEDURE TO PREDICT ESTUARINE WATER QUALITY

6.1.7 Present Water-Quality Assessment

The first step in the estuarine water quality assessment should be the evaluation of existing water quality. Before an analysis of the impact of future waste load changes is made, the planner should know whether or not current estuarine water quality is acceptable, marginal, or substandard.

By far the best way to assess existing water quality is to measure it. The planner should attempt to locate other agencies which might have already collected acceptable samples and/or data. Candidate organizations include the United States Geologic Survey, the U.S. Army Corps of Engineers, state water quality control and monitoring agencies, and engineering and oceanographic departments of local colleges and universities. If such data cannot be located, a data collection program could be undertaken. If at all possible, high tide, and especially low tide in-situ measurements and samples should be collected along the full length of the estuary's main channel and in all significant side embayments. Analyses should then be made in an appropriate laboratory facility. If funds for such data collection efforts are not available, the use of a mathematical estimation of existing water quality is an alternative. The methods presented in subsequent sections and applied to the existing discharges can be used. However, it should be remembered that actual data are preferable to a mathematical estimate of existing water quality.

6.2 ESTUARINE CLASSIFICATION

6.2.1 General

Section 6.1.7 discussed making a first estimate of current estuarine water quality. This section begins a calculation methodology designed to look at the effect of future changes in waste loading patterns.

The goal of the classification process presented below is to predict the applicability of the hand calculations to be presented. The classification process is normally the first step to be taken in the calculation procedure since it reveals which techniques can be applied.

6.2.2 Classification Methodology

The classification system recommended for purposes of hand calculations is based on salinity and velocity profiles within the estuary. As both of these parameters vary seasonally and spatially for each estuary, their use will result in a range of values rather than in one single classification number. The following section will describe in detail the procedure for use of this system, and show examples of the procedure.

6.2.3 Calculation Procedure

Hansen and Rattray (1966) developed an estuarine classification system using both salinity stratification and water circulation patterns (based on water column velocities). This procedure involves the calculation of values for two parameters at various points along the main estuarine channel and the plotting of these intersections on the graph shown in Figure VI-6. Figure VI-7 shows plots made by Hansen and Rattray for various estuaries at a single point in time. It should be noted that each estuary is not represented by a point but by a line connecting the points calculated for the mouth and head areas.

The area designations (e.g. 1a, 1b, 2b) on Figure VI-6 were related by Hansen and Rattray to previously used classification titles (e.g. stratified, well mixed). In general, area 1a corresponds to well mixed estuaries. Area 1b has the water circulation pattern of a well mixed estuary yet shows increased stratification. Areas 2 and 3 correspond to the "partially mixed" class of estuaries with area 3 showing more significant lateral circulation within the estuary. Designations 2a/b and 3a/b, as was true of 1a and 1b, indicate increasing degrees of vertical stratification. Type 3b includes fjord-type estuaries. Area 4 represents highly stratified, salt wedge estuaries.

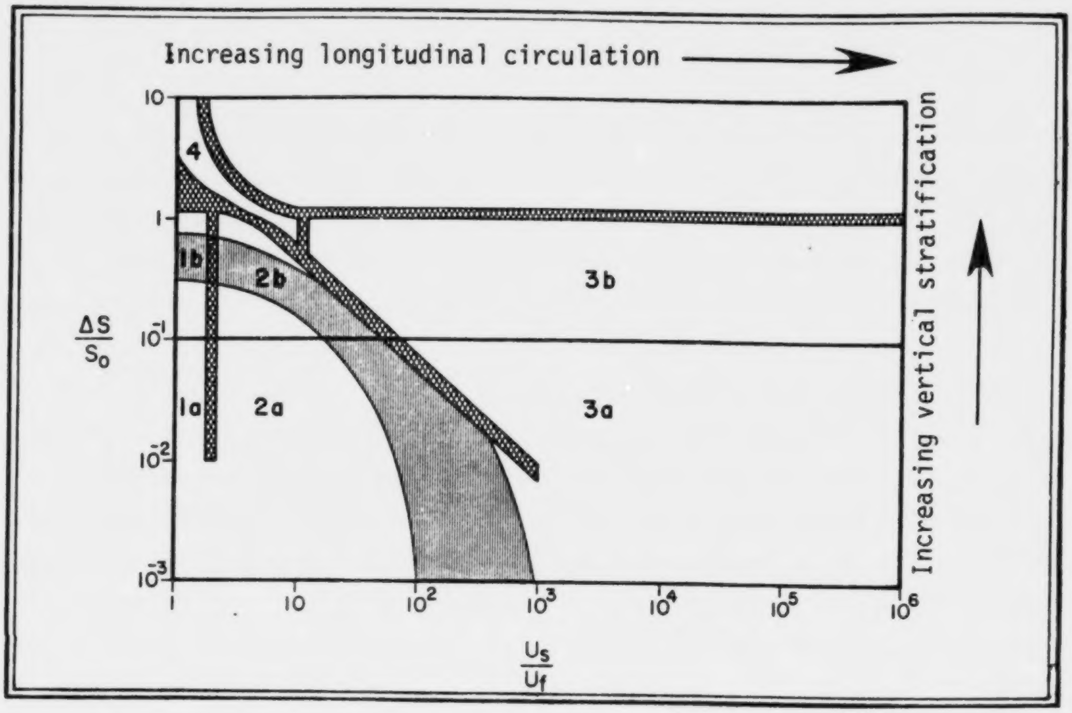
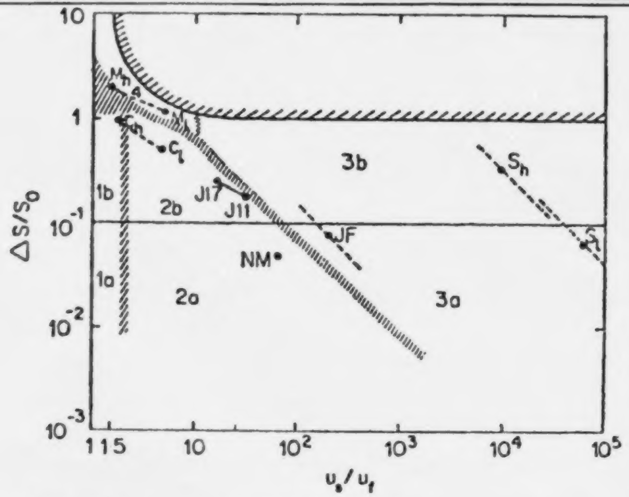


FIGURE VI-6 ESTUARINE CIRCULATION-STRATIFICATION DIAGRAM



(Station code: M, Mississippi River mouth; C, Columbia River estuary; J, James River estuary; NM, Narrows of the Mersey estuary; JF, Strait of Juan de Fuca; S, Silver Bay. Subscripts h and l refer to high and low river discharge; numbers indicate distance (in miles) from mouth of the James River estuary.

FIGURE VI-7 EXAMPLES OF ESTUARINE CLASSIFICATION PLOTS (FROM HANSEN AND RATTRAY, 1966)

6.2.4 Stratification-Circulation Diagram Interpretation

The closer an estuary falls to the lower left hand corner of a stratification-circulation diagram the more vertically and laterally homogeneous it is. On the stratification-circulation diagram (Figure VI-6), two types of zonal demarcation can be seen. First are the diagonally striped divisions between adjacent estuarine classifications used by Hansen and Rattray to indicate a transitional zone between separate classifications. The second is a wide solid band arching around the lower left corner of the diagram. Estuaries falling primarily inside of this band (to the lower left of the band) are those for which the one dimensional calculation methods may be applied to obtain reasonably accurate results. If an estuary falls outside of this band, the planner should use only the methods presented which pertain to stratified estuaries, or use computer analyses. Within the band is a borderline or marginal zone. Calculations for one-dimensional estuaries can be used for estuaries falling principally within this zone, however the accuracy of the calculations will be uncertain.

The two parameters used with the stratification-circulation diagram are described below:

a. Stratification Parameter: The stratification parameter is defined as:

$$\text{Stratification Parameter} \equiv \frac{\Delta S}{S_o} \qquad \text{(VI-1)}$$

where

ΔS = time averaged difference in salinity between surface and bottom water ($S_{bottom} - S_{surface}$), ppt

and,

S_o = cross-section mean salinity, ppt

The diagramatic relationship of these values is shown in Figure VI-8.

b. Circulation Parameter: The circulation parameter is defined as:

$$\text{Circulation parameter} \equiv \frac{U_s}{U_f} \qquad \text{(VI-2)}$$

where

U_s = net non-tidal sectional surface velocity (surface velocity through the section averaged over a tidal cycle) measured in ft/sec. See Figure VI-8 for a diagramatic representation of U_s.

and,

U_f = mean fresh water velocity through the section, ft/sec.

In equation form,

$$U_f = \frac{R}{A} \qquad \text{(VI-3)}$$

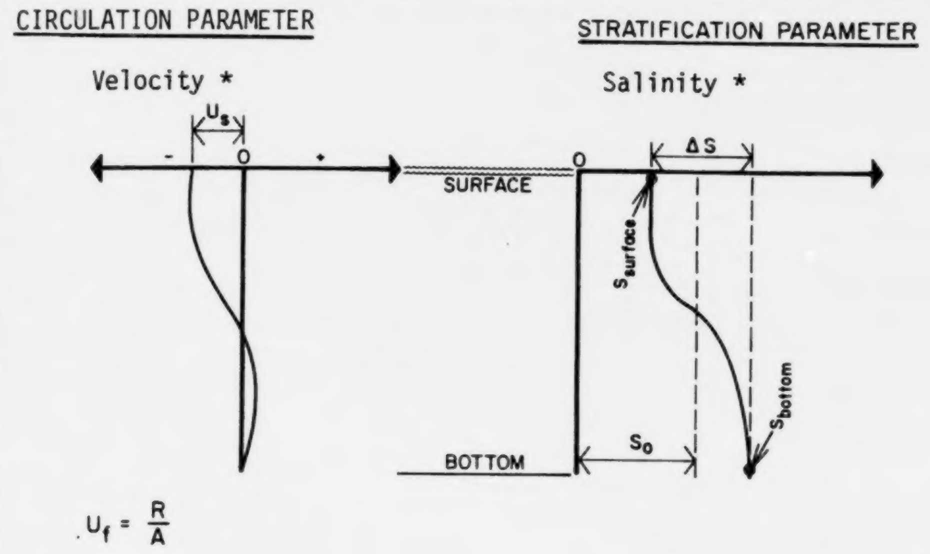
where

R = fresh water (river) inflow rate, ft^3/sec,

and

A = cross-sectional area of the estuary through the point being used to calculate the circulation pattern and stratification parameters based on a mean tide surface elevation, ft^2.

If good cross-sectional area data are not available, cross-sectional profiles can be approximated from the U.S.Geological Survey (USGS) coastal series topographical maps, or, more recently, from NOAA National Ocean Survey charts.



* Both velocity and salinity values for these profiles are averaged over a tidal cycle (net velocity and salinity) rather than being instantaneous values. Of the two the stratification parameter is much less sensitive to variations over a tidal cycle and can be approximated by mean tide values for salinity. Surface velocity (U_s) must be average over a tidal cycle.

FIGURE VI-8 CIRCULATION AND STRATIFICATION PARAMETER DIAGRAM

The circulation and stratification parameters should be plotted for high and low river flow periods and for stations near the mouth and head of the estuary. The area enclosed by these four points should then include the full range of possible instantaneous estuary hydrodynamic characteristics. In interpreting the significance of this plotted area, by far the greater weight should be given to the low river flow periods as these periods are associated with the poorest pollutant flushing characteristics and the lowest estuarine water quality. The interpretation of the circulation-stratification diagrams will be explained more fully after an example of parameter computation.

EXAMPLE VI-1

Calculation of Stratification and Circulation Parameters

The estuary for this example is the Stuart Estuary which is shown in Figure VI-9. The estuary is 64,000 feet long, is located on the U.S. west coast, and is fed by the Scott River. Two stations were selected for parameter calculation (A and B) with station A located on the southern edge of the main channel 6,500 feet from the estuary's mouth and station B in center channel 47,500 feet from the mouth (16,500 feet from the head of the estuary).

Necessary salinity data were obtained from the coastal engineering department of a nearby university. USGS gage data were available for river flow, and, as a result of its own dredging program, the local district office of the U.S. Corps of Engineers could provide cross-sectional profiles in the approximate areas of both stations. The cross-sections are labeled (1) and (2) on Figure VI-9. The mean low tide depth reading on NOAA Coastal charts was used to verify Corps data. Current meters were tied to buoy channel markers at A and B to provide velocity data. The information obtained from these various sources is shown in graphical form in Figure VI-10.

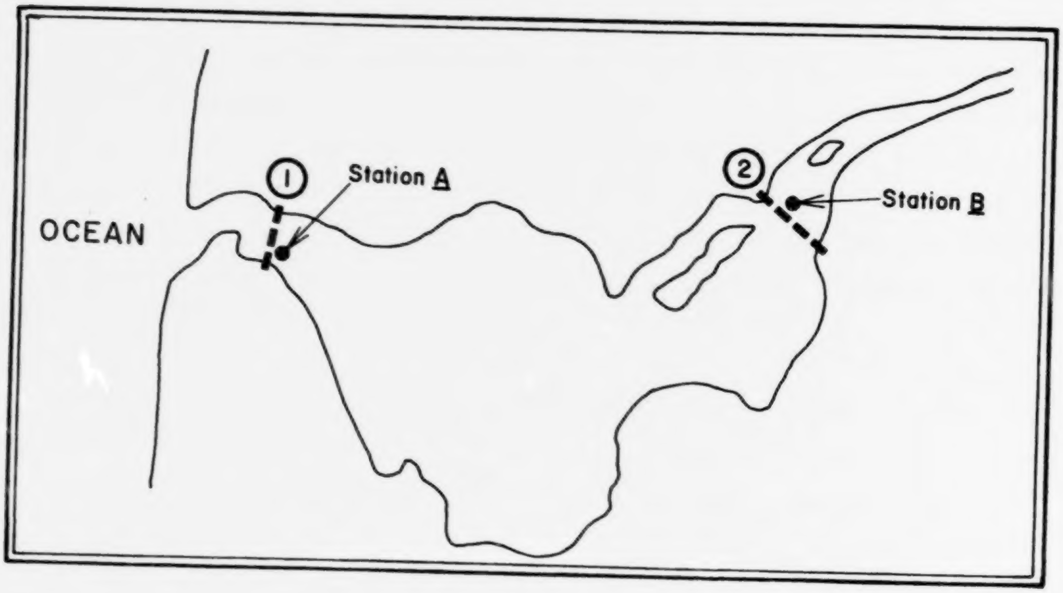


FIGURE VI-9 THE STUART ESTUARY

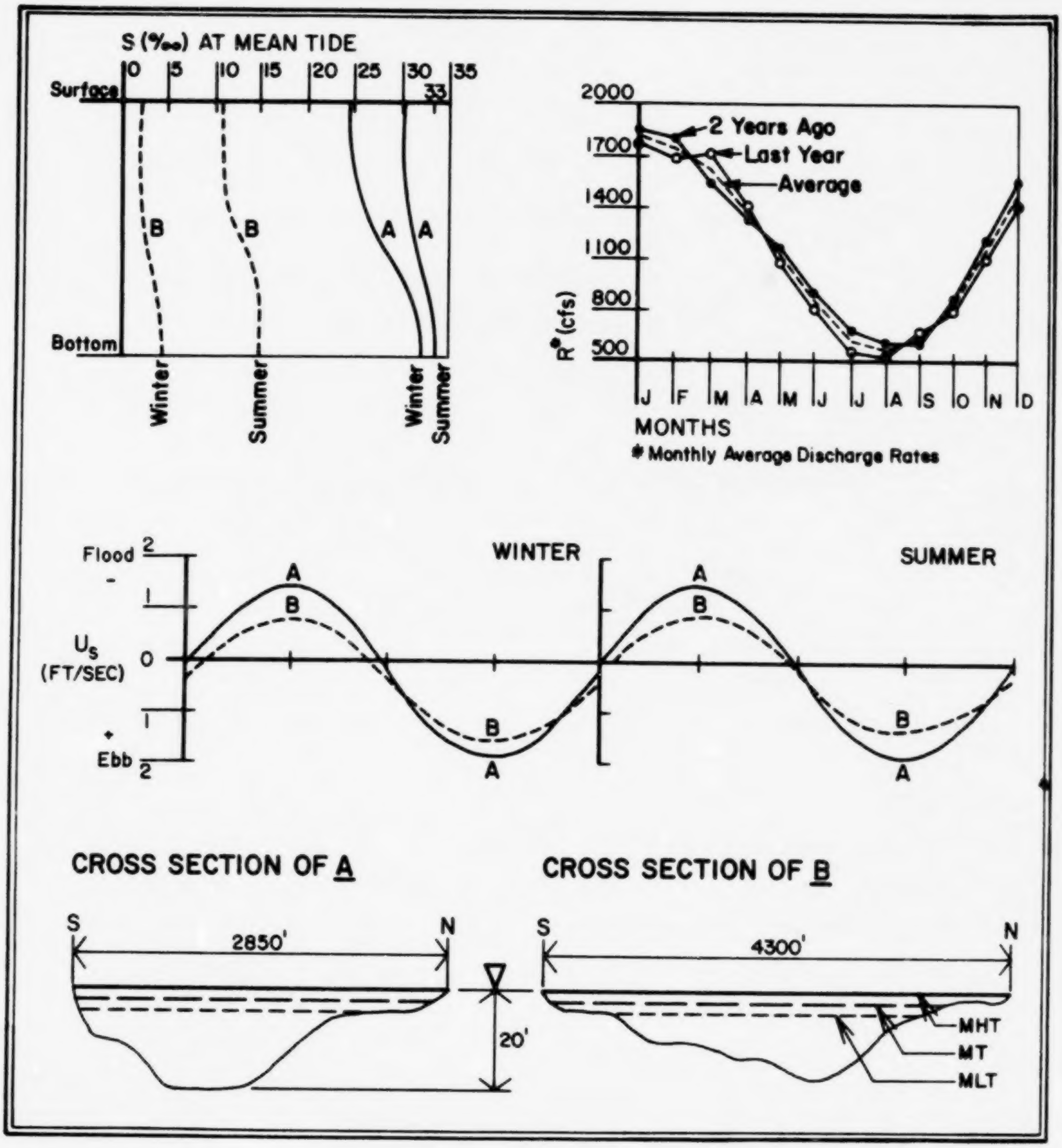


FIGURE VI-10 STUART ESTUARY DATA FOR CLASSIFICATION CALCULATIONS

The calculations proceed as follows:

a. Stratifiction Parameter:

STATION

$\frac{\Delta S}{S_o} = \frac{S_{bottom} - S_{surface}}{S_o}$ →

A	B	
$\frac{33 - 30}{31.5} = \underline{.095}$	$\frac{14.5 - 10.5}{12.5} = \underline{.32}$	SUMMER
$\frac{31.5 - 24.2}{27.8} = \underline{.26}$	$\frac{4 - 2.1}{3.25} = \underline{.58}$	WINTER

b. Circulation Parameter

1. Calculate A_i's using cross sectional information on Figure VI-10

   A_a = (630 ft) (20 ft) (½) + (630 ft) (20 ft) + (1590 ft) (20 ft) (½) = 34,800 ft²

   A_b = (2580 ft) (16 ft) (½) + (1720 ft) (16) (½) = 34,400 ft²

For most cross-sections it is advisable to use more finely divided segments than in the simple example above in order to reduce the error associated with this approximation. The method for this calculation, however, is identical regardless of the number of regular segments used.

2. Calculate U_f's (with R and A_i values obtained from Figure VI-10)

STATION

$U_f = \frac{R}{A_i}$ →

A	B	
$\frac{550\ ft^3/sec}{3.48 \times 10^4\ ft^2} = \underline{1.58 \times 10^{-2}\ ft/sec}$	$\frac{550\ ft^3/sec}{3.44 \times 10^4\ ft^2} = \underline{1.60 \times 10^{-3}\ ft/sec}$	SUMMER
$\frac{1800\ ft^3/sec}{3.48 \times 10^4\ ft^2} = \underline{5.17 \times 10^{-2}\ ft/sec}$	$\frac{1800\ ft^3/sec}{3.44 \times 10^4\ ft^2} = \underline{5.23 \times 10^{-2}\ ft/sec}$	WINTER

3. Calculate $\frac{U_s}{U_f}$'s

U_s values are read from Figure VI-10. The precise value for U_s is the integral of the velocity curve (area under "ebb" velocity curve minus the area under the "flood" velocity curve) divided by the elapsed time period (length of one tidal cycle). If the elapsed time for flood flow at a station is only slightly below the elapsed time for ebb flow U_s may be approximated as $(U_{ebb(max)} - U_{flood(max)})/2$.

	STATION		
	A	B	
$\frac{U_s}{U_f}$ =	$\frac{0.15\ \text{ft/sec}}{1.58\times10^{-2}\ \text{ft/sec}} = \underline{9.5}$	$\frac{0.3\ \text{ft/sec}}{1.60\times10^{-2}\ \text{ft/sec}} = \underline{18.8}$	SUMMER
	$\frac{0.2\ \text{ft/sec}}{5.17\times10^{-2}\ \text{ft/sec}} = \underline{3.9}$	$\frac{0.4\ \text{ft/sec}}{5.23\times10^{-2}\ \text{ft/sec}} = \underline{7.65}$	WINTER

The circulation-stratification plots for the Stuart Estuary are shown in Figure VI-11 with points A_s (station A, summer value), A_w (station A, winter Value), B_s (station B, summer value), and B_w (station B, winter value).

As indicated, this estuary shows a significant amount of vertical stratification (especially at station A) but little evidence of major lateral non-homogeneity.

END OF EXAMPLE VI-1

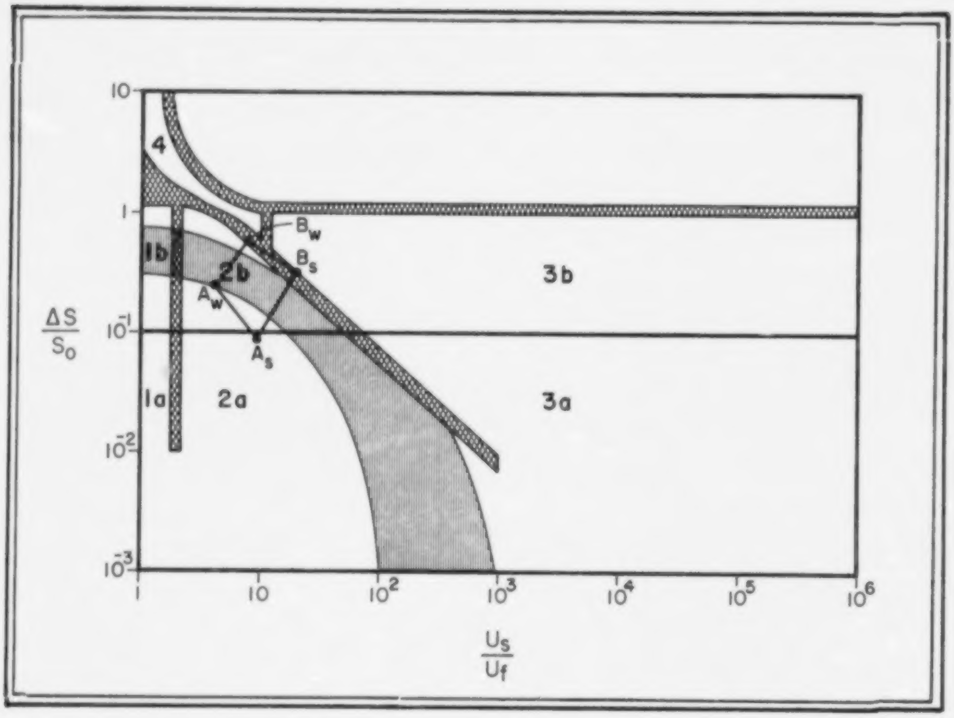


FIGURE VI-11 ESTUARINE CIRCULATION-STRATIFICATION DIAGRAM

Turning to Figure VI-11, the Stratification-Circulation diagram for the Stuart Estuary, it is apparent that this estuary lies principally within the marginal area. Moreover, the low flow classification (line A_s-B_s) also lies primarily within the marginal area. Thus, the planner for the Stuart Estuary should calculate an additional criterion (see below) to help determine the suitability of using the calculation procedures for well mixed estuaries. If the Stuart Estuary plotted more predominately below the marginal zone, the planner could proceed with flushing time calculations since the estuary would then meet the well mixed classification criteria.

It should be noted that the data for the Stuart Estuary produced a fairly tight cluster of data points. As can be seen in Figure VI-12, the salinity profiles for one west coast estuary (the Alsea River and Estuary along the central Oregon coast) vary considerably more from season to season than those of the Stuart Estuary. This increased variation would produce a far greater spread in the summer and winter $\Delta S/S_0$ parameter values.

6.2.5 Flow Ratio Calculation

If application of the above classification procedure results in an ambiguous outcome regarding estuary classification, another criterion should be applied. This is the flow ratio calculation. Schultz and Simmons (1957) first observed the correlation between the flow ratio and estuary type. They defined the flow ratio for an estuary as:

$$F = \frac{R}{P} \qquad \text{(VI-4)}$$

where

F = the flow ratio,

R = the river flow measured over one tidal cycle (measured in m^3 or ft^3)

and

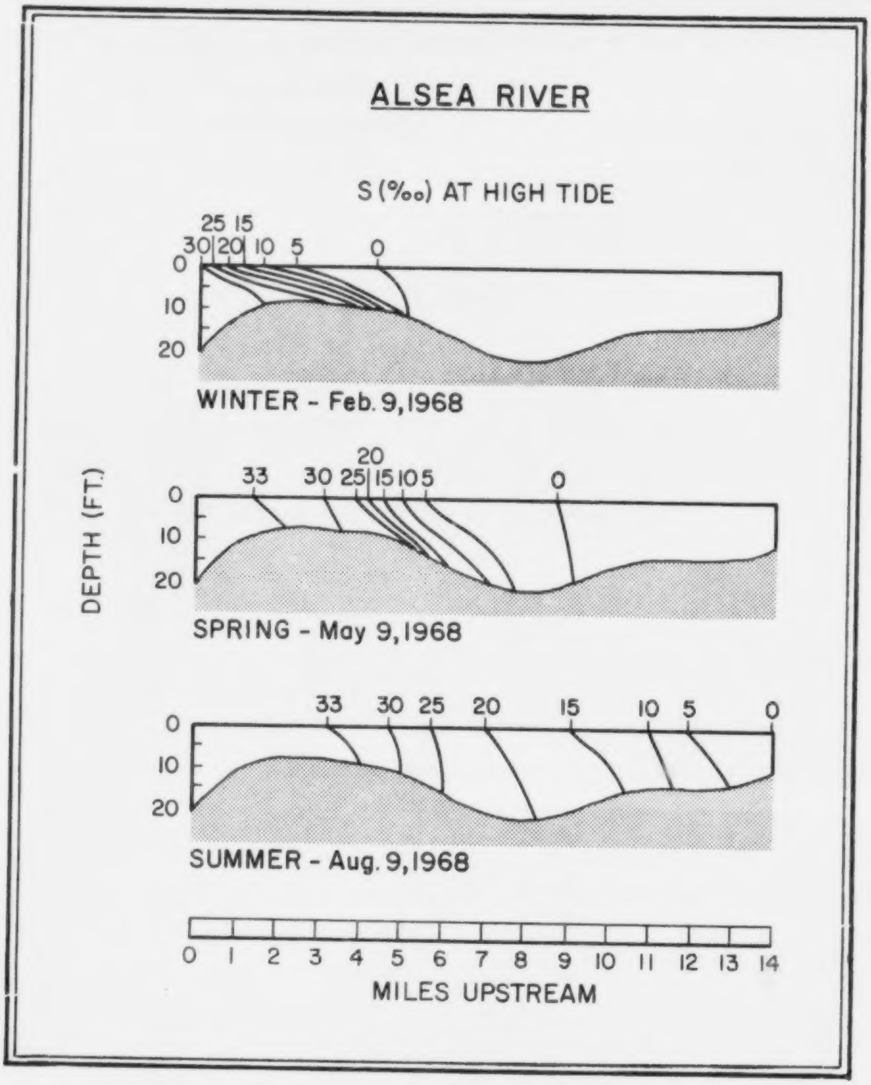


Figure VI-12 Alsea Estuary Seasonal Salinity Variations (From Giger, 1972)

P = the estuary tidal prism (in m^3 or ft^3)

Thus the flow ratio compares the tidally induced flow in an estuary with the river induced flow. Schultz and Simmons observed that when this ratio was on the order of 1.0 or greater, the associated estuary was normally highly stratified. Conversely, ratios of about 0.1 or less were usually associated with very well-mixed estuaries and ratios in the range of 0.25 were associated with partially mixed estuaries. A flow ratio of 0.2 or less warrants inclusion of the estuary in the hand calculation process for one dimensional estuaries. Flow ratios in the range 0.2 to 0.3 should be considered marginal. Estuaries with flow ratios greater than 0.3 should not be included in the one-dimensional category.

EXAMPLE VI-2

Calculation of the Flow Ratio for an Estuary

The following data apply to the Patuxent Estuary, Maryland:

R, total river discharge over one tidal cycle = $1.42 \times 10^5 m^3$ (low flow)
and $3.58 \times 10^6 m^3$ (high flow)
P, estuary tidal prism volume = $3.51 \times 10^7 m^3$

The flow ratios for the Patuxent Estuary at low and high river flows are thus:

$$F = \frac{R}{P}$$

$$F_{\text{low flow}} = \frac{1.42\text{x}10^5 \ m^3}{3.51\text{x}10^7 \ m^3} = 0.004$$

$$F_{\text{high flow}} = \frac{3.58\text{x}10^6 \ m^3}{3.51\text{x}10^7 \ m^3} = 0.10$$

Values of $F \leq 0.1$ are usually associated with well mixed estuaries. The F values calculated above indicate a well mixed estuary. However, historical data indicate the Patuxent River Estuary is partially stratified at moderate and high river flows.

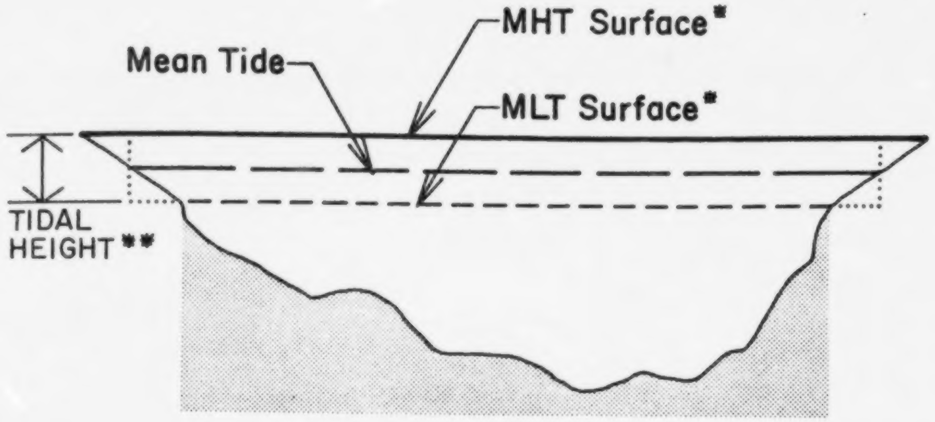
END OF EXAMPLE VI-2

When tidal data are not available, NOAA coastal charts may be used to estimate the difference between mean high tide and mean low tide estuary surface areas. As can be seen in the cross-section diagram in Figure VI-13 the estuarine tidal prism can be approximated by averaging the MLT and MHT surface areas and multiplying this averaged area by the local tidal height. Mean tidal heights (approximately 1 week before or after spring tides) should be used for this calculation. As indicated in Figure VI-13, the estuary can be conveniently subdivided into longitudinal sections for this averaging process, to reduce the resulting error. Table VI-2 lists tidal prisms estimated for many U.S. estuaries. These values may be used as an alternate to tidal prism calculations.

6.3 FLUSHING TIME CALCULATIONS

6.3.1 General

Flushing time is a measure of the time required to transport a conservative pollutant from some specified location within the estuary (usually, but not always, the head) to the mouth of the estuary. Processes such as pollutant decay or sedimentation which can alter the pollutant's distribution within the estuary are not considered in the concept of flushing time.



P_i (section i) = section Length x tidal height x $\left(\frac{\text{MHT width + MLT width}}{2}\right)$

P estuary = $\sum_i P_i$ for all sections

* Widths obtained from NOAA tide table for the area

**Available from local Coast Guard Stations

FIGURE VI-13 ESTUARY CROSS-SECTION FOR TIDAL PRISM CALCULATIONS

TABLE VI-2
TIDAL PRISMS FOR SOME U.S. ESTUARIES
(FROM O'BRIEN, 1969 AND JOHNSON, 1973)

Estuary	Coast	Tidal Prism (ft^3)
Plum Island Sound, Mass.	Atlantic	1.32×10^9
Fire Island Inlet, N.Y.	Atlantic	2.18×10^9
Jones Inlet, N.Y.	Atlantic	1.50×10^9
Beach Haven Inlet (Little Egg Bay), N.J.	Atlantic	1.51×10^9
Little Egg Inlet (Great Bay), N.J.	Atlantic	1.72×10^9
Brigantine Inlet, N.J.	Atlantic	5.23×10^8
Absecon Inlet (before jetties), N.J.	Atlantic	1.65×10^9
Great Egg Harbor Entr, N.J.	Atlantic	2.00×10^9
Townsend Inlet, N.J.	Atlantic	5.56×10^8
Hereford Inlet, N.J.	Atlantic	1.19×10^9
Chincoteague Inlet, Va.	Atlantic	1.56×10^9
Oregon Inlet, N.C.	Atlantic	3.98×10^9
Ocracoke Inlet, N.C.	Atlantic	5.22×10^9
Drum Inlet, N.C.	Atlantic	5.82×10^8
Beaufort Inlet, N.C.	Atlantic	5.0×10^9
Carolina Beach Inlet, N.C.	Atlantic	5.25×10^8
Stono Inlet, S.C.	Atlantic	2.86×10^9
North Edisto River, S.C.	Atlantic	4.58×10^9
St. Helena Sound, S.C.	Atlantic	1.53×10^{10}
Port Royal Sound, S.C.	Atlantic	1.46×10^{10}
Calibogue Sound, S.C.	Atlantic	3.61×10^9
Wassaw Sound, Ga.	Atlantic	8.2×10^9
Ossabaw Sound, Ga.	Atlantic	6.81×10^9
Sapelo Sound, Ga.	Atlantic	7.36×10^9
St. Catherines Sound, Ga.	Atlantic	6.94×10^9

TABLE VI-2 (Cont.)

Estuary	Coast	Tidal Prism (ft^3)
Doboy Sound, Ga.	Atlantic	4.04×10^9
Altamaha Sound, Ga.	Atlantic	2.91×10^9
Hampton River, Ga.	Atlantic	1.01×10^9
St. Simon Sound, Ga.	Atlantic	6.54×10^9
St. Andrew Sound, Ga.	Atlantic	9.86×10^9
Ft. George Inlet, Fla.	Atlantic	3.11×10^8
Old St. Augustine Inlet, Fla.	Atlantic	1.31×10^9
Ponce de Leon, Fla. (before jetties)	Atlantic	5.74×10^8
Delaware Bay Entrance	Atlantic	1.25×10^{11}
Fire Island Inlet, N.Y.	Atlantic	1.86×10^9
East Rockaway Inlet, N.Y.	Atlantic	7.6×10^8
Rockaway Inlet, N.Y.	Atlantic	3.7×10^9
Masonboro Inlet, N.C.	Atlantic	8.55×10^8
St. Lucie Inlet, Fla.	Atlantic	5.94×10^8
Nantucket Inlet, Mass.	Atlantic	4.32×10^8
Shinnecock Inlet, N.Y.	Atlantic	2.19×10^8
Moriches Inlet, N.Y.	Atlantic	1.57×10^9 8.46×10^8
Shark River Inlet, N.J.	Atlantic	1.48×10^8
Manasguan Inlet, N.J.	Atlantic	1.75×10^8
Barnegat Inlet, N.J.	Atlantic	6.25×10^8
Absecon Inlet, N.J.	Atlantic	1.48×10^9
Cold Springs Harbor (Cape May), N.J.	Atlantic	6.50×10^8
Indian River Inlet, Del.	Atlantic	5.25×10^8
Winyah Bay, S.C.	Atlantic	3.02×10^9
Charleston, S.C.	Atlantic	5.75×10^9
Savannah River (Tybee Roads), Ga.	Atlantic	3.1×10^9

TABLE VI-2 (Cont.)

Estuary	Coast	Tidal Prism (ft^3)
St. Marys (Fernandina Harbor), Fla.	Atlantic	4.77×10^9
St. Johns River, Fla.	Atlantic	1.73×10^9
Fort Pierce Inlet, Fla.	Atlantic	5.81×10^8
Lake Worth Inlet, Fla.	Atlantic	9.0×10^8
Port Everglades, Fla.	Atlantic	3.0×10^8
Bakers Haulover, Fla.	Atlantic	3.6×10^8
Captiva Pass, Fla.	Gulf of Mexico	1.90×10^9
Boca Grande Pass, Fla.	Gulf of Mexico	1.26×10^{10}
Gasparilla Pass, Fla.	Gulf of Mexico	4.7×10^8
Stump Pass, Fla.	Gulf of Mexico	3.61×10^8
Midnight Pass, Fla.	Gulf of Mexico	2.61×10^8
Big Sarasota Pass, Fla.	Gulf of Mexico	7.6×10^8
New Pass, Fla.	Gulf of Mexico	4.00×10^8
Longboat Pass, Fla.	Gulf of Mexico	4.90×10^8
Sarasota Pass, Fla.	Gulf of Mexico	8.10×10^8
Pass-a-Grille	Gulf of Mexico	1.42×10^9
Johns Pass, Fla.	Gulf of Mexico	5.03×10^8
Little (Clearwater) Pass, Fla.	Gulf of Mexico	6.8×10^8
Big (Dunedin) Pass, Fla.	Gulf of Mexico	3.76×10^8
East (Destin) Pass, Fla.	Gulf of Mexico	1.62×10^9
Pensacola Bay Entr., Fla.	Gulf of Mexico	9.45×10^9
Perdido Pass, Ala.	Gulf of Mexico	5.84×10^8
Mobile Bay Entr., Ala.	Gulf of Mexico	2.0×10^{10}
Barataria Pass, La.	Gulf of Mexico	2.55×10^9
Caminada Pass, La.	Gulf of Mexico	6.34×10^8
Calcasieu Pass, La.	Gulf of Mexico	2.97×10^9
San Luis Pass, Tex.	Gulf of Mexico	5.84×10^8

TABLE VI-2 (Cont.)

Estuary	Coast	Tidal Prism (ft^3)
Venice Inlet, Fla.	Gulf of Mexico	8.5×10^7
Galveston Entr., Tex.	Gulf of Mexico	1.59×10^{10}
Aransas Pass, Tex.	Gulf of Mexico	1.76×10^9
Grays Harbor, Wash.	Pacific	1.3×10^{10}
Willapa, Wash.	Pacific	1.3×10^{10}
Columbia River, Wash.-Ore.	Pacific	2.9×10^{10}
Necanicum River, Ore.	Pacific	4.4×10^7
Nehalem Bay, Ore.	Pacific	4.3×10^8
Tillamook Bay, Ore.	Pacific	2.5×10^9
Netarts Bay, Ore.	Pacific	5.4×10^8
Sand Lake, Ore.	Pacific	1.1×10^8
Nestucca River, Ore.	Pacific	2.6×10^8
Salmon River, Ore.	Pacific	4.3×10^7
Devils Lake, Ore.	Pacific	1.1×10^8
Siletz Bay, Ore.	Pacific	3.5×10^8
Yaquina Bay, Ore.	Pacific	8.4×10^8
Alsea Estuary, Ore.	Pacific	5.1×10^8
Siuslaw River, Ore.	Pacific	2.8×10^8
Umpqua, Ore.	Pacific	1.2×10^9
Coos Bay, Ore.	Pacific	1.9×10^9
Caquille River, Ore.	Pacific	1.3×10^8
Floras Lake, Ore.	Pacific	6.8×10^7
Rogue River, Ore.	Pacific	1.2×10^8
Chetco River, Ore.	Pacific	2.9×10^7
Smith River, Ca.	Pacific	9.5×10^7
Lake Earl, Ca.	Pacific	5.1×10^8
Freshwater Lagoon, Ca.	Pacific	4.7×10^7
Stove Lagoon, Ca.	Pacific	1.2×10^8
Big Lagoon, Ca.	Pacific	3.1×10^8

TABLE VI-2 (Cont.)

Estuary	Coast	Tidal Prism (ft^3)
Mad River, Calif.	Pacific	2.4×10^7
Humbolt Bay, Calif.	Pacific	2.4×10^9
Eel River, Calif.	Pacific	3.1×10^8
Russian River, Calif.	Pacific	6.3×10^7
Bodega Bay, Calif.	Pacific	1.0×10^8
Tomales Bay, Calif.	Pacific	1.0×10^9
Abbotts Lagoon, Calif.	Pacific	3.5×10^7
Drakes Bay, Calif.	Pacific	2.7×10^8
Bolinas Lagoon, Calif.	Pacific	1.0×10^8
San Francisco Bay, Calif.	Pacific	5.2×10^{10}
Santa Cruz Harbor, Calif.	Pacific	4.3×10^6
Moss Landing, Calif.	Pacific	9.4×10^7
Morro Bay, Calif.	Pacific	8.7×10^7
Marina Del Rey, Calif.	Pacific	6.9×10^7
Alamitos Bay, Calif.	Pacific	6.9×10^7
Newport Bay, Calif.	Pacific	2.1×10^8
Camp Pendleton, Calif.	Pacific	1.1×10^7
Aqua Hedionda, Calif.	Pacific	4.9×10^7
Mission Bay, Calif.	Pacific	3.3×10^8
San Diego Bay, Calif.	Pacific	1.8×10^9

It was mentioned earlier in this chapter that the net non-tidal flow in an estuary is usually seaward* and is dependent on the river discharge. The non tidal flow is one of the driving forces behind estuarine flushing. In the absence of this advective displacement, tidal oscillation and wind stresses still operate to disperse and flush pollutants. However, the advective component of flushing can be extremely important. Consider Tomales Bay, California as an example. This small, elongated bay has essentially no fresh water inflow. As a result there is no advective seaward motion and pollutant removal is dependent upon dispersion and diffusion processes. The flushing time for the bay is approximately 140 days (Johnson, et al., 1961). This can be compared with the Alsea Estuary in Oregon having a flushing time of approximately 8 days, with the much larger St. Croix Estuary in Nova Scotia having a flushing time of approximately 8 days (Ketchum and Keen, 1951), or with the very large Hudson River Estuary with a short flow flushing time of approximately 10.5 days (Ketchum, 1950).

6.3.2 Procedure

Flushing times for a given estuary vary over the course of a year as river discharge varies. The critical time is the low river flow period since this period corresponds with the minimum flushing rates. The planner might also want to calculate the best flushing characteristics (high river flow) for an estuary. In addition to providing a more complete picture of the estuarine system, knowledge of the full range of annual flushing variations can be useful in evaluating the impact of seasonal discharges (e.g. fall and winter cannery operation in an estuary with a characteristic summer fresh water low flow). Further, storm sewer runoff normally coincides with these best flushing conditions (high flow) and not with the low flow, or poorest flushing conditions. Thus analysis of storm runoff is often better suited for high flow flushing conditions. However, the low flow calculation should be considered for use in primary planning purposes.

*While net flow is always seaward for the estuaries being considered here, it is possible to have a net upstream flow in individual embayments of an estuary. While this occurrence is rare in the United States, an example of such a situation is the South Bay of San Francisco Bay where freshwater inflows are so small that surface evaporation exceeds freshwater inflow. Thus, net flow is upstream during most of the year.

There are several ways of calculating flushing time. Two methods are presented here: the fraction of freshwater method and the modified tidal prism method.

6.3.3 Fraction of Fresh Water Method

The flushing time of a pollutant, as determined by the fraction of freshwater method is

$$T_f = \frac{V_f}{R} \tag{VI-5}$$

where

V_f = volume of freshwater in the estuary

T_f = flushing time of a pollutant which enters the head of the estuary with the river flow

Equation VI-5 is equivalent to the following concept of flushing time which is more intuitively meaningful:

$$T_f = \frac{M}{\dot{M}} \tag{VI-6}$$

where

M = total mass of conservative pollutant contained in the estuary

$\dot{M}$ = rate of pollutant entry into the head of the estuary with the river water

Since the volume of freshwater in the estuary is the product of the fraction of freshwater (f) and the total volume of water (V), Equation VI-5 becomes:

$$T_f = \frac{fV}{R} \qquad \text{(VI-7)}$$

If the estuary is divided into segments the flushing time becomes:

$$T_f = \Sigma \frac{f_i V_i}{R_i} \qquad \text{(VI-8)}$$

Equation VI-8 is more general and accurate than the three previous expressions because both f_i (the fraction of freshwater in the ith segment) and R_i (the freshwater discharge through the ith segment) can vary over distance within the estuary. Note that the flushing time of a pollutant discharged from some location other than the head of the estuary can be computed by summing contributions over the segments seaward of the discharge.

A limitation of the fraction of freshwater method is that it assumes uniform salinity throughout each segment. A second limitation is that it assumes during each tidal cycle a volume of water equal to the river discharge moves into a given estuarine segment from the adjacent upstream segment, and that an equal volume of the water originally in the segment moves on to the adjacent one downstream. Once this exchange has taken place, the water within each segment is assumed to be instantaneously and completely mixed and to again become a homogeneous water mass. Proper selection of estuarine segments can reduce these errors.

6.3.4 Calculation of Flushing Time by Fraction of Freshwater Method

This is a six step procedure:

1. Graph the estuarine salinity profiles.

2. Divide the estuary into segments. There is no minimum or maximum number of segments required, nor must all segments be of the same length. The divisions should be selected so that mean segment salinity is relatively constant over the full

length of the segment. Thus, stretches of steep salinity gradient will have short segments and stretches where salinity remains constant may have very long segments. Example VI-3 provides an illustration.

3. Calculate each segment's fraction of fresh water by:

$$f_i = \frac{S_s - S_i}{S_s} \qquad \text{(VI-9)}$$

where

f_i = fraction of fresh water for segment "i"

S_s = salinity of local sea water*, $^o/oo$

and

S_i = mean salinity for segment "i", $^o/oo$

4. Calculate the quantity of fresh water in each segment by:

$$W_i = f_i \times V_i \qquad \text{(VI-10)}$$

where

W_i = quantity of fresh water in segment "i"

and

V_i = total volume of segment"i" at MTL

*Sea surface salinity along U.S. shores vary spatially. Neuman and Pierson (1966) mapped Pacific mean coastal surface salinities as varying from 32.4 $^o/oo$ at Puget Sound to 33.9 $^o/oo$ at the U.S.-Mexico border; Atlantic mean coastal surface salinities as varying from 32.5 $^o/oo$ in Maine to 36.2 $^o/oo$ at the southern extreme of Florida; and Gulf coast salinities as varying between 36.2 $^o/oo$ and 36.4 $^o/oo$. Surface coastal salinities in Long Island Sound (Hardy, 1972) and off Long Island south coast (Hydroscience, 1974) vary between 26.5 and 28.5 $^o/oo$.

5. Calculate the exchange time (flushing time) for each segment by:

$$T_i = W_i/R \qquad \text{(VI-11)}$$

where

T_i = segment flushing time, in tidal cycles

and

R = river discharge over one tidal cycle

6. Calculate the entire estuary flusing time by summing the exchange times for the individual segments:

$$T_f = \sum_{i=1}^{n} T_i \qquad \text{(VI-12)}$$

where

T_f = estuary flushing time, in tidal cycles

n = number of segments.

Table VI-3 shows a suggested method for calculating flushing time by the fraction of freshwater method.

TABLE VI-3

SAMPLE CALCULATION TABLE FOR CALCULATION OF FLUSHING TIME BY SEGMENTED FRACTION OF FRESHWATER METHOD

Segment Number	Mean Segment Salinity S_i(ppt)	Mean Segment Length (m)	Mean Segment Cross-sectional Area (m^2)	Segment Mean Tide Volume V_i (m^3)	Fraction of River Water $f_i = \frac{Ss-Si}{Ss}$	River Water Volume $W_i = f_i x V_i$ (m^3)	Segment Flushing Time $T_i = W_i/R$ (tidal cycles)

Up Estuary ↓

$$\sum_{i=1}^{n} T_i =$$

EXAMPLE VI-3

Flushing Time Calculation by Fraction of Fresh Water Method

This example pertains to the Patuxent Estuary. This estuary has no major side embayments, and the Patuxent River is by far its largest source of fresh water. This estuary therefore lends itself well to analysis by the segmented fraction of fresh water method.

Salinity profiles for July 19, 1978 are used to find segment salinity values. Chesapeake Bay water at the mouth of the Patuxent Estuary had a salinity of 10.7 ppt (S_i). The Patuxent River discharge over the duration of one tidal cycle is

$$\begin{aligned} R &= (12\ \mathrm{m^3/sec})(12.4\ \mathrm{hr/tidal\ cycle})(3600\ \mathrm{sec/hr}) \\ &= 5.36 \times 10^5\ \mathrm{m^3/tidal\ cycle} \end{aligned}$$

A segmentation scheme based on the principles laid out above is used to divide the estuary into eight segments; their measured characteristics are shown Table VI-4. The segmentation is shown graphicaly on the estuary salinity profile (Figure VI-14).

The next step is to find the fraction of fresh water for each segment. For segment 1,

$$f_1 = \frac{S_s - S_1}{S_s}$$

where

f_1 = fraction of fresh water, segment 1

S_s = salinity of local seawater

TABLE VI-4

PATUXENT ESTUARY SEGMENT CHARACTERISTICS FOR FLUSHING TIME CALCULATIONS

Segment Number	Mean Segment Salinity S_i, ppt	Segment Length meters	Mean Segment Cross-Sectional Area meter^2	Mean Tide Segment Volume V_i meters^3
8	10.3	10,400	16,000	16.6×10^7
7	9.5	10,400	12,500	13.0×10^7
6	8.7	6,100	11,400	6.95×10^7
5	7.6	6,100	7,500	4.58×10^7
4	5.8	5,800	4,300	2.49×10^7
3	3.3	5,000	3,100	1.55×10^7
2	1.8	4,650	2,200	1.02×10^7
1	0.8	4,650	1,700	0.79×10^7

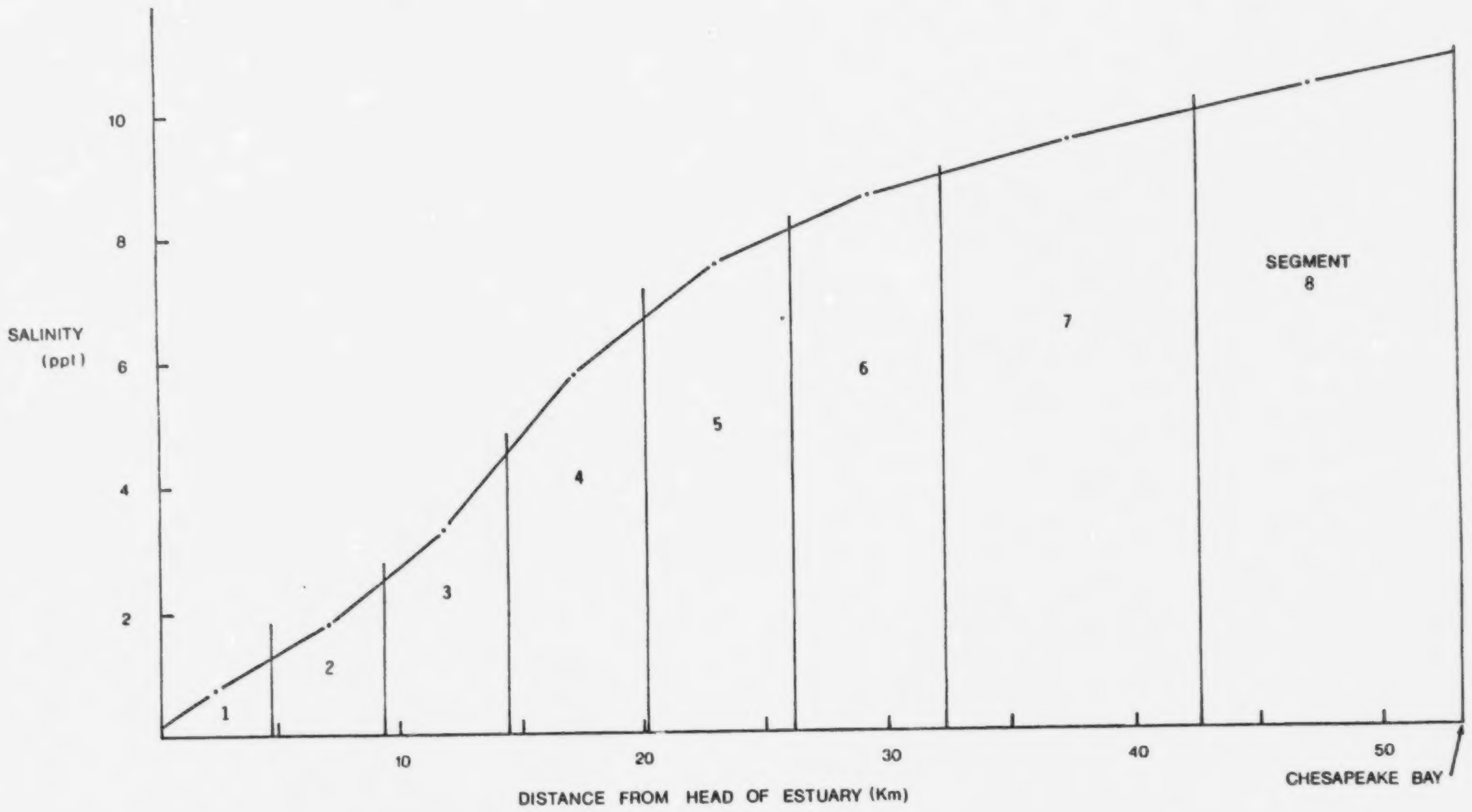


FIGURE VI-14 PATUXENT ESTUARY SALINITY PROFILE AND SEGMENTATION SCHEME USED IN FLUSHING TIME CALCULATIONS.

S_1 = measured mean salinity for segment 1

$$f_1 = \frac{10.7\text{ ppt}-0.8\text{ ppt}}{10.7\text{ ppt}} = 0.93$$

The calculation is reported in Table VI-4 for segments 2 through 8.

The volume of fresh water (river water) in each segment is next found using the formula

$$W_i = f_i \times V_i$$

For segment 1,

$$W_1 = f_1 \times V_1 = 0.93\ (0.79 \times 10^7 m^3)$$
$$= 7.35 \times 10^6 m^3$$

The flushing time for each segment is next calculated by

$$T_i = W_i/R$$

For segment 1,

$$T_1 = W_1/R = 7.35 \times 10^6 m^3/(5.36 \times 10^5 m^3/\text{tidal cycle})$$
$$= 13.7 \text{ tidal cycles}$$

Fraction of freshwater, river water volume and flushing time values for the eight segments are compiled in Table VI-5.

The final step is to determine the flushing time for the estuary. In this case,

$$T_f = \sum_{i=1}^{8} T_i =$$

$$11.4 + 27.2 + 24.6 + 24.8 + 21.5 + 20.0 + 15.8 + 13.7$$

$$= 159 \text{ tidal cycles, or } 2.74 \text{ months}$$

TABLE VI-5

FLUSHING TIME FOR PATUXENT ESTUARY

Segment Number	Mean Segment Salinity S_i, ppt	Segment Length meters	Mean Segment Cross-Sectional Area meter^2	Segment Mean Tide Volume V_i meter^3	Fraction of River Water $f_i = \frac{S_s - S_i}{S_s}$ (S_s = 10.7)	River Water Volume $W_i = f_i \times V_i$ (meters^3)	Segment Flush Time $T_i = W_i/R$ tidal cycles
8	10.3	10,400	16,000	16.6×10^7	0.037	6.14×10^6	11.4
7	9.5	10,400	12,500	13.0×10^7	0.112	14.6×10^6	27.2
6	8.7	6,100	11,400	6.95×10^7	0.19	13.2×10^6	24.6
5	7.6	6,100	7,500	4.58×10^7	0.29	13.3×10^6	24.8
4	5.8	5,800	4,300	2.49×10^7	0.46	11.5×10^6	21.5
3	3.3	5,000	3,100	1.55×10^7	0.69	10.7×10^6	20.0
2	1.8	4,650	2,200	1.02×10^7	0.83	8.47×10^6	15.8
1*	0.8	4,650	1,700	0.79×10^7	0.93	7.35×10^6	13.7

Sum = 159 tidal cycles
or 2.74 months

---

*In this numbering scheme segment 1 is the most upstream segment.

END OF EXAMPLE VI-3

6.3.5 Branched Estuaries and the Fraction of Freshwater Method

Branched estuaries, where more than one source of freshwater contributes to the salinity distribution pattern, are common. The fraction of freshwater method can be directly applied to estuaries of this description. Consider the estuary shown in Figure VI-15, having two major sources of freshwater (River 1, R_1; and River 2, R_2). The flushing time for pollutants entering the estuary with river flow R_2 is:

$$T_f\ (R_2) = T_1 + T_2 + T_3 + T_4 + T_5 + T_6 =$$

$$\frac{f_1V_1}{R_2} + \frac{f_2V_2}{R_2} + \frac{f_3V_3}{R_2} + \frac{f_4V_4}{R_2} + \frac{f_5V_5}{R_1+R_2} + \frac{f_6V_6}{R_1+R_2}$$

For the pollutants entering with R_1, the flushing time is:

$$T_f\ (R_1) = \frac{f_aV_a}{R_1} + \frac{f_bV_b}{R_1} + \frac{f_cV_c}{R_1} + \frac{f_5V_5}{R_1+R_2} + \frac{f_6V_6}{R_1+R_2}$$

The flushing time computations are similar in concept for the case of a single freshwater source, modified to account for a flow rate of $R_1 + R_2$ in segments 5 and 6.

6.3.6 Modified Tidal Prism Method

This method divides an estuary into segments whose lengths are defined by the maximum excursion path of a water particle during a tidal cycle. Within each segment the tidal prism is compared to the total segment volume as a measure of the flushing potential of that segment per tidal cycle (Dyer, 1973). The method assumes complete mixing of the incoming tidal prism waters with the low tide volumes within each segment. Best results have been obtained in estuaries when the number of segments is large (i.e.

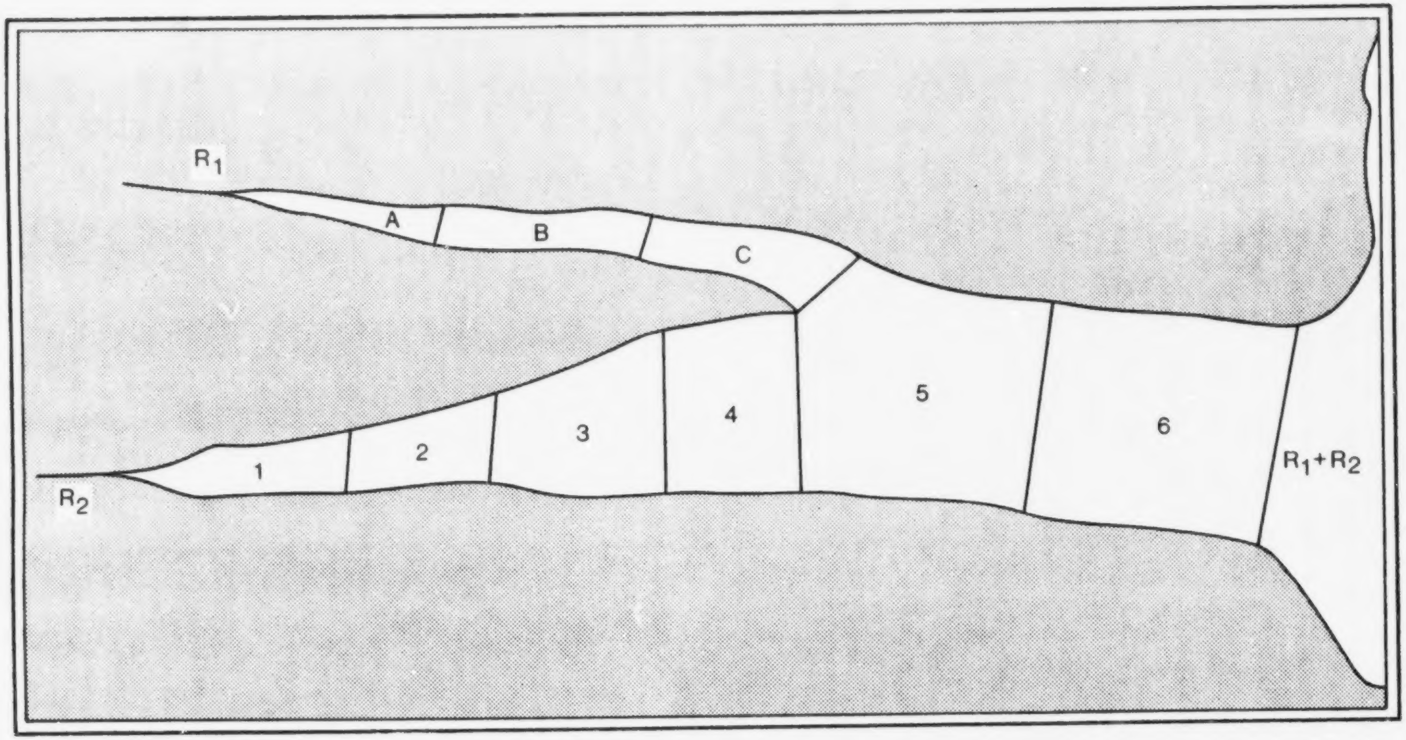


FIGURE VI-15 HYPOTHETICAL TWO-BRANCHED ESTUARY

when river flow is very low) and when estuarine cross-sectional area increases fairly quickly downstream (Dyer, 1973).

The modified tidal prism method does not require knowledge of the salinity distribution. It provides some concept of mean segment velocities since each segment length is tied to particle excursion length over one tidal cycle. A disadvantage of the method is that in order to predict the flushing time of a pollutant discharged midway down the estuary, the method still has to be applied to the entire estuary.

The modified tidal prism method is a four-step methodology. The steps are:

1. Segment the estuary. For this method an estuary must be segmented so that each segment length reflects the excursion distance a particle can travel during one tidal cycle. The innermost section must then have a tidal prism volume completely supplied by river flow. Thus,

   $$P_0 = R$$

   where

   P_0 = tidal prism (intertidal volume) of segment "0"

   and

   R = river discharge over one tidal cycle.

   The low tide volume in this section (V_0) is that water volume occupying the space under the intertidal volume P_0 (which has just been defined as being equal to R). The seaward limit of the next seaward segment is placed such that its low tide volume (V_1) is defined by:

   $$V_1 = P_0 + V_0 \qquad \text{(VI-13)}$$

P_1 is then that intertidal volume which, at high tide, resides above V_1. Successive segments are defined in an identical manner to this segment so that:

$$V_i = P_{i-1} + V_{i-1} \qquad \text{(VI-14)}$$

Thus each segment contains, at high tide, the volume of water contained in the next seaward section at low tide.

2. Calculate the exchange ratio (r) by:

$$r_i = \frac{P_i}{P_i+V_i} \qquad \text{(VI-15)}$$

Thus the exchange ratio for a segment is a measure of a portion of water associated with that segment which is exchanged with adjacent segments during each tidal cycle.

3. Calculate segment flushing time by:

$$T_i = \frac{1}{r_i} \qquad \text{(VI-16)}$$

where

T_i = flushing time for segment "i", measured in tidal cycles.

4. Calculate total estuarine flushing time by summing the individual segment flushing times:

$$T_f = \sum_{i=1}^{n} T_i \qquad \text{(VI-17)}$$

where

T_f = total estuary flushing time

and

n = number of segments.

Table VI-6 shows a suggested method for calculating flushing time by the modified tidal prism method.

EXAMPLE VI-4

Estuary Flushing Time Calculation by the Modified Tidal Prism Method

The Fox Mill Run Estuary, Virginia, was selected for this example. During low flow conditions, the discharge of Fox Mill Run has been measured at 0.031 m^3/sec.

R = river discharge over one tidal cycle

= 0.031 m^3/sec x 12.4 hrs/tidal cycle x 3600 sec/hr

= 1384 m^3/tidal cycle.

The estuary flushing time is found in four steps:

1. Segmentation

From bathymetric maps and tide gage data, cumulative upstream volume was plotted for several positions along the estuary (See Figure VI-16).

TABLE VI-6

SAMPLE CALCULATION TABLE FOR ESTUARINE FLUSHING TIME BY THE MODIFIED TIDAL PRISM METHOD

Down Estuary ↓

Segment Number	Segment Dimensions				Subtidal Water Volume, V_i (m^3)	Intertidal Water Volume P_i (m^3)	Segment Exchange Ratio r_i	Segment Flushing Time, T_i (Tidal Cycles)
	Starting Distance Above Mouth (m)	Ending Distance Above Mouth (m)	Distance of Center Above Mouth (m)	Segment Length (m)				
							$\sum_{i=1}^{n} T_i =$	

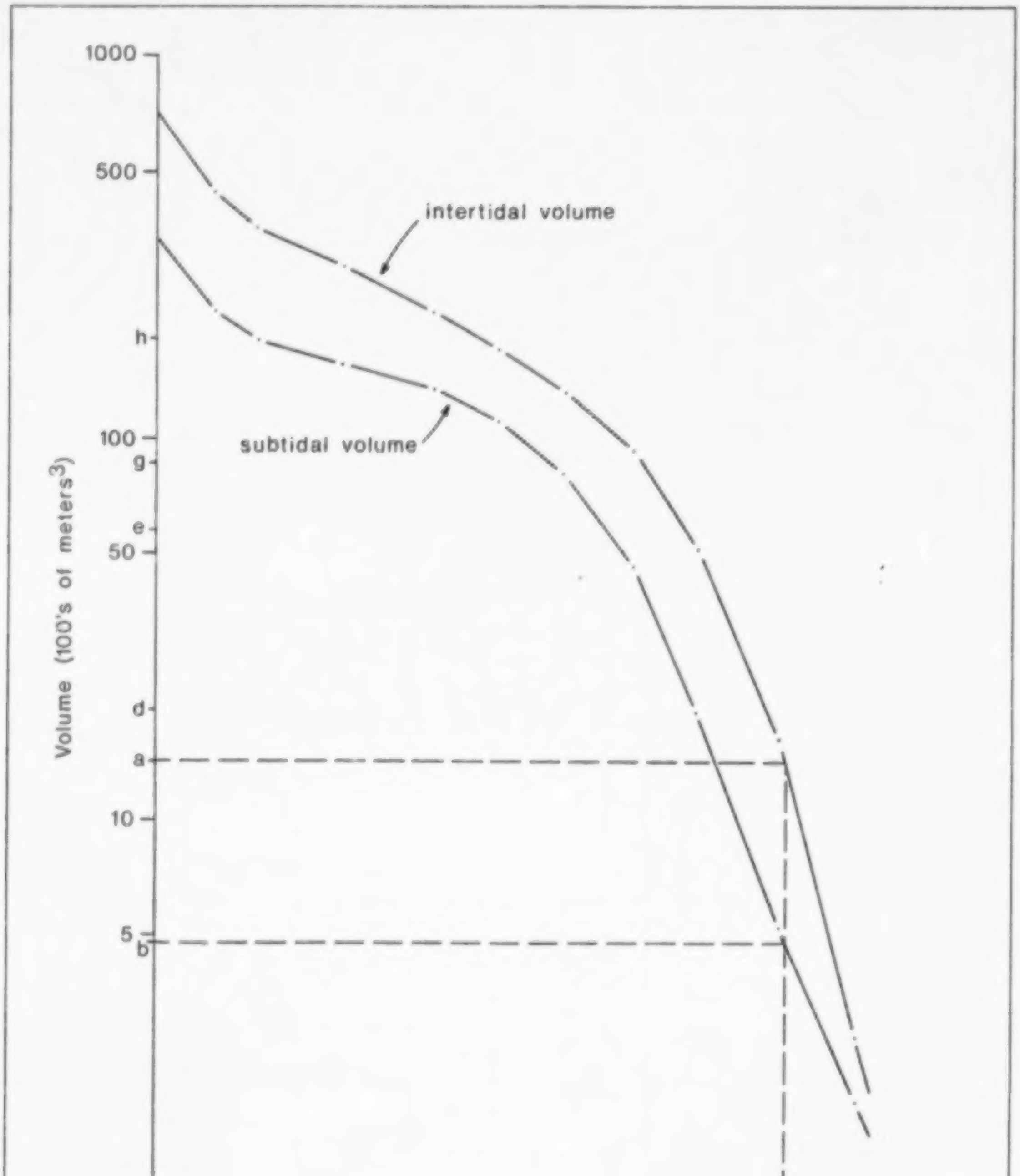


FIGURE VI-16 CUMULATIVE UPSTREAM WATER VOLUME, FOX MILL RUN ESTUARY

Since

$$P_0 = R$$

$$P_0 = 1384 \text{ m}^3.$$

Reading across the graph from "a" to the intertidal volume curve, then down the subtidal volume curve and across to "b",

$$V_0 = 490 \text{ m}^3.$$

The known cumulative upstream water volume also establishes the downstream segment boundary. Reading downward from the subtidal volume curve to "c", a V_0 of 490 m³ corresponds to an upstream distance of 2,700 meters for the segment 0 lower boundary.

The low tide water volume for the next segment can be found by the equation:

$$V_1 = P_0 + V_0$$

or

$$V_1 = 1384 + 490 = 1874 \text{ m}^3$$

Since the graphs of Figure VI-16 are cumulative curves, it is necessary, when entering a V_i value in order to determine a P_i value, to sum the upstream V_i's. For V_1 the cumulative upstream low-tide volume is:

$$V_0 + V_1 = 490 + 1874 = 2364 \text{ m}^3$$

Entering the graph where the subtidal volume is equal to 2,364 m³ (across from "d"), we can move upward to read the corresponding cumulative intertidal volume "e" on the vertical scale, and downward to read the downstream boundary of segment 1 at "f" on the horizontal scale. The cumulative upstream intertidal volume is 5900 m³. Since

$$5900 \text{ m}^3 = P_0 + P_1$$

$$P_1 = 5900-1384 = 4516 \text{ m}^3$$

For segment 2,

$$V_2 = P_1 + V_1 = 1874 + 4516 = 6390 \text{ m}^3$$

To find P_2, it is necessary to enter the graph at a cumulative subtidal volume of

$$V_0 + V_1 + V_2 = 490 + 1874 + 6390 = 8759 \text{ m}^3 \text{(across from "g")}$$

This yields a cumulative intertidal volume of 14,000 m³ (across from "h") and a downstream segment boundary of 1,650 m³ "i".

The tidal prism of Segment 2 is found by:

$$14000 = P_0 + P_1 + P_2$$

or

$$P_2 + 14000 - 1384 - 4516 + 8100 \text{ m}^3$$

The procedure is identical for Segment 3. For this final segment,

$$V_3 = 14,490 \text{ m}^3$$

and

$$P_3 = 36,000 \text{ m}^3$$

Dimensions and volumes of the four segments established by this procedure are compiled in Table VI-7.

2. The exchange ratio for segment 0 is found by

$$r_0 = \frac{P_0}{P_0+V_0} = \frac{1384 \text{ m}^3}{1384 \text{ m}^3+490 \text{ m}^3}$$

TABLE VI-7

DATA AND FLUSHING TIME CALCULATIONS FOR FOX MILL RUN ESTUARY

Segment Number	Segment Dimensions				Water Volume at Low Tide V_i meters³	Intertidal Volume P_i meters³	Exchange Ratio For Segment i r_i	Flushing Time for Segment i T_i
	Starts at this Distance Above Mouth meters	Stops at this Distance Above Mouth meters	Center Point Distance Above Mouth meters	Segment Length meters				
0	3,200	2,700	2,950	500	490	1,384	0.74	1.35
1	2,700	2,240	2,470	460	1,874	4,516	0.71	1.41
2	2,240	1,650	1,945	590	6,390	8,100	0.56	1.79
3	1,650	180	915	1,470	14,490	36,000	0.71	1.41

ΣT_i = 5.96 tidal cycles

Exchange ratios are calculated similarly for the other three segments.

3. Flushing time for each segment "i" is given by

$$T_i = \frac{1}{r_i}$$

so

$$T_o = \frac{1}{r_o} = \frac{1}{0.74} = 1.35$$

Exchange ratios and flushing times for the four segments are shown in Table VI-7.

4. Flushing time for the whole estuary is found by

or
$$T_f = \sum_{i=o}^{3} T_i$$

$$\begin{aligned} T = 1.35+1.41+1.79+1.41 &= 5.96 \text{ tidal cycles} \\ &= 73.9 \text{ hours} \\ &= 3.1 \text{ days} \end{aligned}$$

END OF EXAMPLE VI-4

6.4 FAR FIELD APPROACH TO POLLUTANT DISTRIBUTION IN ESTUARIES

6.4.1 Introduction

Analysis of pollutant distribution in estuaries can be accomplished in a number of ways. In particular, two approaches, called the far field and near field approaches, are presented here (Sections 6.4 and 6.5, respectively). As operationally defined in this document, the far field approach ignores buoyancy and momentum effects of the wastewater as it is discharged into the estuary. The pollutant is assumed to be instantaneously distributed over the entire cross-section of the estuary (in the case of a well-mixed estuary) or to be distributed over a lesser portion of the estuary in the case of a two-dimensional analysis. Whether or not these assumptions are realistic depends on a variety of factors, including the rapidity of mixing compared to the kinetics of the process being analyzed (e.g. compared to dissolved oxygen depletion rates). It should be noted that far field analysis (either one- or two- dimensional) can be used even if actual mixing is less than assumed by the method. However, the predicted pollutant concentrations will be lower than the actual concentrations.

Near field analysis considers the buoyancy and momentum of the wastewater as it is discharged into the receiving water. Pollutant distribution can be calculated on a smaller spatial scale, and assumptions such as "complete mixing" or "partial mixing" do not have to be made. The actual amount of mixing which occurs is predicted as an integral part of the method itself. This is a great advantage in analyzing compliance with water quality standards which are frequently specified in terms of a maximum allowable pollutant concentration in the receiving water at the completion of initial dilution. (Initial dilution will be defined later in Section 6.5.2)

The following far field approaches for predicting pollutant distribution are presented in this chapter:

- fraction of freshwater method,
- modified tidal prism method,
- dispersion-advection equations, and

- Pritchard's Box Model.

The near field analysis uses tabulated results from an initial dilution model called MERGE. At the completion of initial dilution predictions can be made for the following:

- pollutant concentrations
- pH levels, and
- dissolved oxygen concentrations.

The near field pollutant distribution results are then used as input to an analytical technique for predicting pollutant decay or dissolved oxygen levels subsequent to initial dilution. The remainder of Section 6.4 will discuss those methods applicable to the far field approach.

6.4.2 Continuous Flow of Conservative Pollutants

The concentration of a conservative pollutant entering an estuary in a continuous flow varies as a function of the entry point location. It is convenient to separate pollutants entering an estuary at the head of the estuary (with the river discharge) from those entering along the estuary's sides. The two impacts will then be addressed separately.

6.4.2.1 River Discharges of Pollutants

The length of time required to flush a pollutant from an estuary after it is introduced with the river discharge has already been calculated, and is the estuarine flushing time. Now consider a conservative pollutant continuously discharged into a river upstream of the estuary. As pollutant flows into the estuary, it begins to disperse and move toward the mouth of the estuary with the net flow. If, for example, the estuary flushing time is 10 tidal cycles, 10 tidal cylces following its initial flow into the estuary, some of the pollutant is flushed out to the ocean. Eventually, a steady-state condition is reached in which a certain amount of pollutant enters the estuary, and the same amount is flushed out of the estuary during each tidal cycle. The amount of this pollutant which resides in the estuary at steady-state is a function of the flushing time. From the definition of flushing time, the amount of fresh water (river water) in the estuary may be calculated by:

$$W_E = T_f R \qquad \text{(VI-18)}$$

where

W_E = quantity of freshwater in the estuary

T_f = estuary flushing time

and

R = river discharge over one tidal cycle.

Using the same approach, the quantity of freshwater in any segment of the estuary is given by:

$$W_i = T_i R \qquad \text{(VI-19)}$$

where

W_i = quantity of freshwater in the i^{th} segment of the estuary

and

T_i = flushing time for the i^{th} segment calculated by the fraction of freshwater method.

If a conservative pollutant enters an estuary with the river flow, it can be assumed that its steady-state distribution will be identical to that of the river water itself. Thus,

$$M_i = W_i\ C_r = T_i\ R\ C_r \qquad \text{(VI-20)}$$

and

$$C_i = W_i/V_i \qquad \text{(VI-21)}$$

where

M_i = quantity of pollutant in estuary segment "i"

C_r = concentration of pollutant in the river inflow

C_i = concentration of pollutant in estuary segment "i" assuming all of pollutant "i" enters the estuary with the river discharge. Thus direct discharges into the estuary are excluded

and

V_i = water volume segment "i".

The same values for C_i and M_i may also be obtained by using the fraction of freshwater, f_i, for each segment by:

$$C_i = f_i\ C_r \qquad \text{(VI-22)}$$

and

$$M_i = C_i V_i \qquad \text{(VI-23)}$$

Thus both the quantity of a pollutant in each segment and its concentration within each segment are readily obtainable by either of the above methods. The use of one of these methods will be demonstrated in Example VI-5 below for calculation of both C_i and M_i.

EXAMPLE VI-5

Calculation of Concentration of Conservative River Borne Pollutant in an Estuary

The Patuxent Estuary is the subject of this example. The problem is to predict the incremental concentration increase of total nitrogen (excluding N_2 gas) in the estuary, given that the concentration in river water at the estuary head is 1.88 mgN/l.

Assume that total nitrogen is conservative and that the nitrogen concentration in local seawater is negligible. The segmentation scheme used in Example VI-2 (fraction of freshwater calculation) will be retained here. For each segment, the total nitrogen concentration is directly proportional to the fraction of freshwater in the segment:

$$C_i = f_i C_r$$

The total nitrogen concentration for the uppermost segment is therefore given by:

$$C_1 = 0.93 \text{ (1.88 mgN/l)} = 1.75 \text{ mgN/l}$$

For the next segment it is:

$$C_2 = 0.83\ (1.88\ \text{mgN/l}) = 1.56\ \text{mgN/l}, \quad \text{and so on.}$$

Nitrogen concentrations for all the segments are compiled in Table VI-8. Note that these are not necessarily total concentrations, but only nitrogen inputs from the Patuxent River.

The incremental mass of nitrogen in each segment is found by:

$$M_i = W_i\ C_r$$

The W_i values for the eight segments were determined in Example VI-2. For segment 1, the incremental nitrogen is given by:

$$M_1 = W_1\ C_r$$

$$= (7.35\text{x}10^6\text{m}^3)(1.88\ \text{mgN/l})(10^3\text{l/m}^3)$$

$$= 1.38\text{x}10^{10}\ \text{mg or } 13{,}800\ \text{kg}$$

Increased total nitrogen (in kilograms) for the entire estuary is shown in Table VI-9.

END OF EXAMPLE VI-5

In this example, low tide volumes were used to calculate M_i since low tide volumes had been used to calculate f_i's. The approach assumes that C_i's are constant over the tidal cycle and that M_i's are constant over the tidal cycle. This leads to the assumption that calculation of a low tide C_i and M_i will fully characterize a pollutant in an estuary. This, however, is not strictly true. Figure VI-17 depicts one tidal cycle in an estuary and

TABLE VI-8

POLLUTANT DISTRIBUTION IN THE PATUXENT RIVER

Segment Number*	Fraction of Freshwater* in Segment f_i	Resultant Pollutants** Concentration $= f_i \times 1.88$ mgN/l
8	0.037	0.07
7	0.112	0.21
6	0.19	0.36
5	0.29	0.55
4	0.46	0.86
3	0.69	1.30
2	0.83	1.56
1	0.93	1.88
River	1.00	1.88

* From Example VI-2

** These are the increment concentrations of total nitrogen in the estuary due to the river-borne input.

TABLE VI-9

INCREMENTAL TOTAL NITROGEN IN PATUXENT RIVER, EXPRESSED AS KILOGRAMS

(See Problem VI-5)

Segment Number	River Water Volume $W_i=f_i xV$ meters^3	Incremental Total N $M_i = W_i(1.88)$ kilograms
8	$6.14x10^6$	11,500
7	$14.6x10^6$	27,40
6	$13.2x10^6$	24,800
5	$13.3x10^6$	25,000
4	$11.5x10^6$	21,600
3	$10.7x10^6$	20,100
2	$8.47x10^6$	15,900
1	$7.35x10^6$	13,800

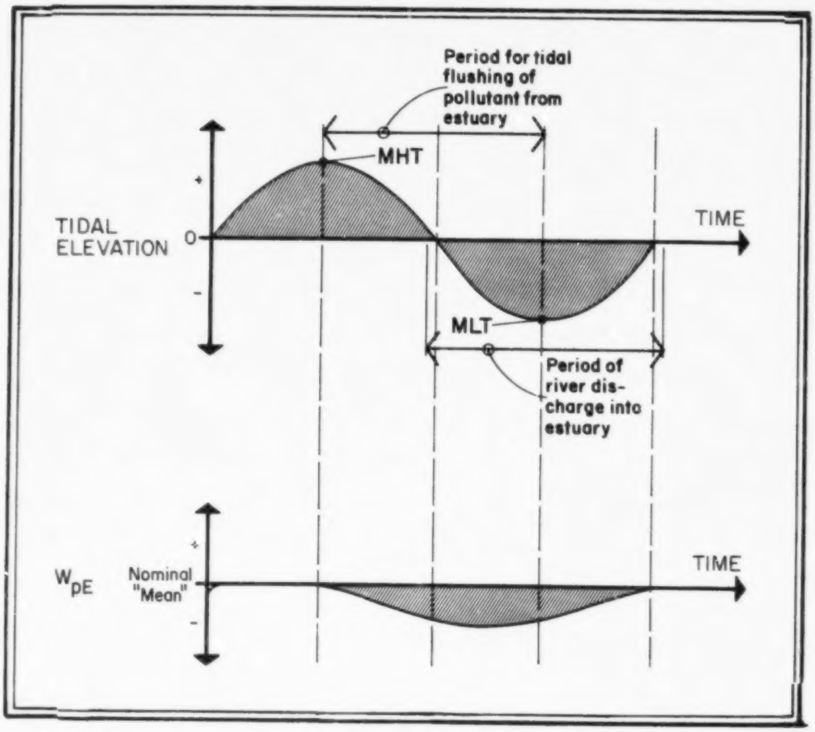


FIGURE VI-17 RIVER BORNE POLLUTANT CONCENTRATION FOR ONE TIDAL CYCLE

shows the periods of the cycle during which a pollutant is flushed out of the estuary and during which river discharge brings pollutants into the estuary. During periods of high tide, rising tidal elevation blocks river discharge and backs up river flow in the lower stretches of the river. Figure VI-17 also shows the resulting quantity of a pollutant in residence in the estuary (W_{pe}) over the tidal cycle. This variation over the tidal cycle as a percentage of M_E is dependent on the flushing time but is usually small. The change in the total volume of water in an estuary over a tidal cycle is equal to the tidal prism which is often of the same magnitude as the low tide volume. As an example, the Alsea Estuary in Oregon has P_t = 5.1×10^8 ft^3 while $V_t = 2.1 \times 10^8$ (Goodwin, Emmet, and Glenne, 1970). Thus the variation in estuarine volume is 2.5 times the low tide volume. As a result, estuarine volume variations over a tidal cycle have a much greater impact on variations in pollutant concentrations in the estuary than do changes in the quantity of pollutant present in the estuary over a tidal cycle. It is important to note, however, that low tidal volume and low M_E nearly coincide, so that variations in mean pollutant concentrations are less severe than are estuarine water mass changes.

This qualitative description of pollutant flow into and out of an estuary is somewhat simplistic since it assumes that high tide and low tide at the mouth of an estuary coincide with those at the head of the estuary. This is usually not the case. There is normally a lag time between tidal events at an estuarine mouth and those at its head. Thus river discharge into the estuary which depends on tidal conditions at the head, and tidal discharge which depends on tidal conditions at the mouth, are not as directly tied to each other as indicated in Figure VI-17.

While W_E does not vary substantially over a tidal cycle under steady-state conditions, the mean concentration of a pollutant in an estuary (C_E) does. Alsea Estuary data can be used to show this C_E variation over a tidal cycle. Using data for the estuary as a whole (mean concentration), the equations for this comparison are:

$$W_E = W_r \, T_f \qquad \text{(VI-24)}$$

and

$$C_E = M_E/(V_t\ P_t), \qquad \text{(VI-25)}$$

with

$$W_r = (566.4\ \mu g/ft^3)\ (4.64x10^6\ ft^3/\text{tidal cycle}),$$

or

$$W_r = 2.628x10^9\ \mu g/\text{tidal cycle}.$$

Then,

$$M_E = (2.628x10^9\ \mu g/\text{tidal cycle})(20.8\ \text{tidal cycle}),$$

$$M_E = 5.466x10^{10}\ ug,$$

and

$$C_{E(low)} = 5.466x10^{10}\ \mu g/2.1x10^8\ ft^3,$$

or

$C_{E(low)} = 260.31\ \mu g/ft^3$, or 46 percent of river concentration.

However,

$$C_{E(high)} = 5.466x10^{10}\ \mu g/(2.1x10^8\ ft^3 + 5.1x10^8\ ft^3),$$

$C_{E(high)} = 75.92\ \mu g/ft^3$, or 13 percent of river concentration.

In an actual estuary, the concentration of a pollutant is not a stepwise function as indicated by segment C_i values, but is more realistically a continuous spectrum of values. By assigning the longitudinal midpoint of each segment a concentration value equal to that segment's C_i, a resulting continuous curve can be constructed as shown in Figure VI-18. This type of plot is useful in estimating pollutant concentrations within the estuary. It can also be used, however, to estimate maximum allowable C_r to maintain a given level of water quality at any point within the estuary. This latter use of Figure VI-18 is based on determining the desired concentration level (C_x) and then using the ratio of C_x to C_r to calculate an allowable C_r.

6.4.2.2 Other Continuous Conservative Pollutant Inflows

In the previous section, an analysis was made of the steady-state distribution of a continuous flow pollutant entering at the head of an estuary. The result was a graph of the longitudinal pollutant concentration within the estuary (Figure VI-18). This section addresses a continuous, conservative pollutant flow entering along the side of an estuary. Such a pollutant flow (e.g. the conservative elements of a municipal sewer discharge, industrial discharge, or minor tributary) is carried both upstream and downstream by tidal mixing, with the highest concentration occurring in the vicinity of the outfall. Once a steady state has been achieved, the distribution of this pollutant is directly related to the distribution of fresh river water (Dyer, 1973).

The average cross-sectional concentration at the outfall under steady-state conditions is:

$$C_o \simeq \frac{Q_p}{R} f_o \qquad \text{(VI-26)}$$

where

C_o = mean cross-sectional concentration of a pollutant at the point of discharge, mass/volume

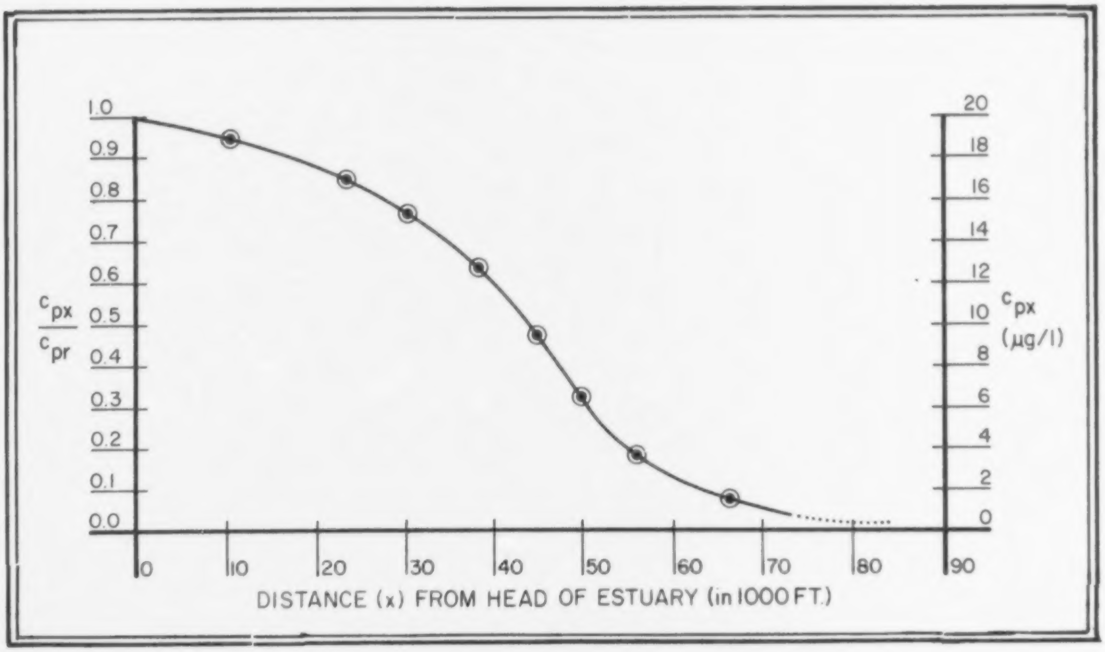


FIGURE VI-18 ALSEA ESTUARY RIVERBORNE CONSERVATIVE POLLUTANT CONCENTRATION

Q_p = discharge rate of pollutant, mass/tidal cycle

f_o = segment fraction of freshwater

R = river discharge rate, volume/tidal cycle.

Downstream of the outfall, the pollutant must pass through any cross section at a rate equal to the rate of discharge. Thus,

$$C_x = C_o \frac{f_x}{f_o} = C_o \left(\frac{\frac{S_s - S_x}{S_s}}{\frac{S_s - S_o}{S_s}} \right) = C_o \left(\frac{S_s - S_x}{S_s - S_o} \right) = f_x \frac{Q_p}{R} \qquad \text{(VI-27)}$$

where

S_x, C_x and f_x denote downstream cross-sectional values

and

S_o, C_o and f_o denote the cross-sectional vaues at the discharge point (or segment into which discharge is made).

Upstream of the outfall, the quantity of pollutant diffused and advectively carried upstream is balanced by that carried downstream by the nontidal flow so that the net pollutant transport through any cross section is zero. Thus, the pollutant distribution is directly proportional to salinity distribution and (Dyer, 1973):

$$C_x = C_o \frac{S_x}{S_o} \qquad \text{(VI-28)}$$

Downstream of the outfall, the pollutant concentration resulting from a point discharge is directly proportional to river-borne pollutant concentration. Upstream from the discharge point, it is inversely proportional to river-borne pollutant concentrations. Figure VI-19 is a

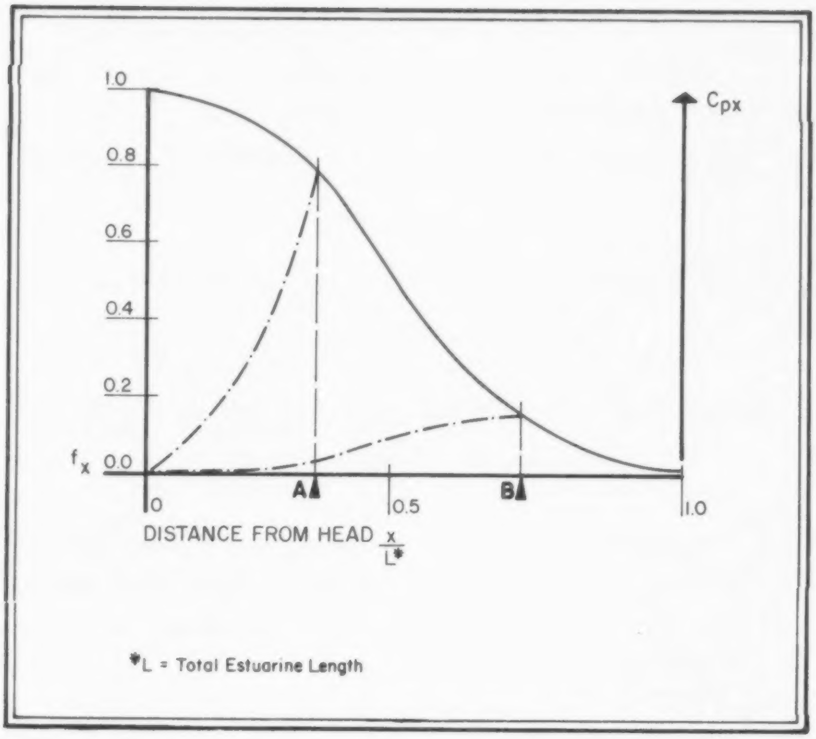


FIGURE VI-19 POLLUTANT CONCENTRATION FROM AN ESTUARINE OUTFALL (AFTER KETCHUM, 1950)

graph of f_x versus distance from the estuary head for a typical estuary. The solid f_x line is also a measure of pollutant concentration for all points downstream of a pollutant outfall (either discharge location A or B). The actual concentration (C_x) for any point is equal to this f_x value multiplied by Q_p/R which is a constant over all x. Upstream concentrations decrease from C_0 in a manner proportional to upstream salinity reduction (see dotted lines). It is important to note how even a small downstream shift in discharge location creates a very significant reduction in upstream steady-state pollutant concentration. Table VI-10 shows a suggested format for tabulating pollutant concentrations by the fraction of freshwater method.

EXAMPLE VI-6

Calculation of Conservative Pollutant Concentration for a Local Discharge

This example will again utilize the eight-segment scheme devised for the Patuxent Estuary in Example VI-2. The objective is to predict the concentration distribution of total nitrogen in the estuary resulting from a discharge of 80,000 mgN/sec into segment 4.

The first step is to determine the nitrogen concentration in segment 4. From Equation VI-26,

$$C_o = \frac{Q_p}{R} f_o = \frac{(8\text{x}10^4\text{mgN/secx12.4 hrs/tidal cyclex3600 sec/hr})(0.46)}{5.36\text{x}10^5 \text{ m}^3\text{/tidal cycle}}$$

$$= \frac{3065 \text{ mgN}}{\text{m}^3} = 3.065 \text{ mgN/l}$$

For segments 1-3, upstream from the discharge, nitrogen concentration is found by Equation VI-28,

$$C_i = C_o \frac{S_i}{S_o}$$

TABLE VI-10

SAMPLE CALCULATION TABLE FOR DISTRIBUTION OF A LOCALLY DISCHARGED CONSERVATIVE POLLUTANT BY THE FRACTION OF FRESHWATER METHOD

From Table VI-3					
Segment Number	Fraction of Freshwater f_i	Mean Segment Salinity (ppt)	$\frac{f_i}{f_o}$	$\frac{S_i}{S_o}$	Pollutant Concentrations* (mg/l)
Segment Containing Discharge			1	1	

← Up Estuary

$$\text{*Pollutant concentration} = \begin{cases} C_o \dfrac{f_i}{f_o}\text{, down estuary of the discharge} \\ C_o \dfrac{S_i}{S_o}\text{, up estuary of the discharge} \end{cases}$$

where $C_o = \frac{W}{R} f_o$

For segment 1,

$$S_1 = 0.8\ ‰$$

$$S_o = S_4 = 5.8\ ‰$$

$$C_4 = 3.065 \text{ mgN/l}$$

so

$$C_1 = 3.065 \text{ mgN/l} \left(\frac{0.8\ ‰}{5.8\ ‰}\right) = 0.42 \text{ mgN/l}$$

Nitrogen concentrations in segments 2 and 3 are found in an identical way. Table VI-11 summarizes the information used in the calculation.

For the segments downstream of the discharge, total nitrogen concentration is found using Equation VI-27,

$$C_i = C_o \frac{f_i}{f_o}$$

In segment 5,

$$f_5 = 0.29$$

$$f_o = f_4 = 0.46$$

and

$$C_4 = 3.065 \text{ mgN/l}$$

so

$$C_5 = 3.065 \text{ mgN/l} \left(\frac{0.29}{0.46}\right) = 1.93 \text{ mgN/l}$$

TABLE VI-11

NITROGEN CONCENTRATION IN PATUXENT ESTUARY BASED ON LOCAL DISCHARGE

	Segment Number	Fraction of Freshwater f_i	Mean Segment Salinity	$\frac{S_i}{S_o}$	$\frac{f_i}{f_o}$	Concentration mgN/l
	8	0.037	10.3	-	0.08	0.25
	7	0.112	9.5	-	0.24	0.74
	6	0.19	8.7	-	0.41	1.26
	5	0.29	7.6	-	0.63	1.93
Discharge →	4	0.46	5.8	1	1	3.06
	3	0.69	3.3	0.57	-	1.75
	2	0.83	1.8	0.31	-	0.95
	1	0.93	0.8	0.14	-	0.43

The same procedure yields nitrogen concentrations in segments 6-8, also downstream of the discharge.

Figure VI-20 below shows the nitrogen concentration distribution over the entire estuary. Note that the nearer a discharge is to the estuary's mouth, the greater the protection rendered the upstream reaches of the estuary.

END OF EXAMPLE VI-6

6.4.3 Continuous Flow Non-Conservative Pollutants

Most pollutant discharges into estuaries have some components which behave non-conservatively. A number of processes mediate the removal of compounds from natural waters, among these:

- sorption by benthic sediments on suspended matter
- partitioning
- decay (by photolysis or biologically mediated reactions)
- biological uptake
- precipitation
- coagulation.

The latter two processes are particularly significant in estuaries. Thus, in addition to dispersion and tidal mixing, a time-dependent component is incorporated when calculating the removal of non-conservative pollutants from estuarine waters. The concentrations of non-conservative pollutants are always lower than those of conservative pollutants (which have a decay rate of zero) for equal discharge concentrations. The results of the previous section for conservative constituents serve to set upper limits for

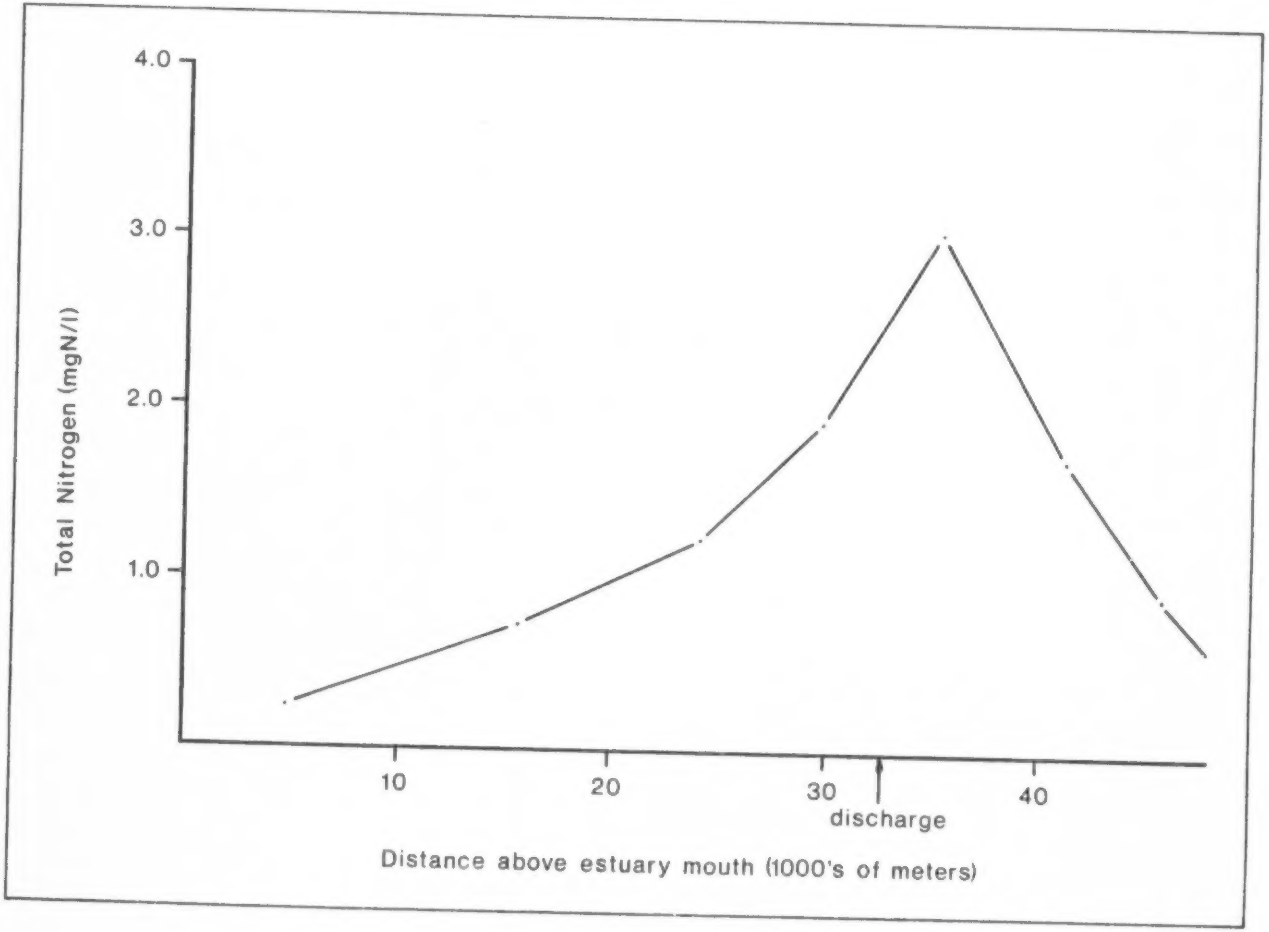


FIGURE VI-20 HYPOTHETICAL CONCENTRATION OF TOTAL NITROGEN IN PATUXENT ESTUARY

the concentration of non-conservative continuous flow pollutants. Thus, if plots similar to Figure VI-17 for river discharges and to Figure VI-19 for other direct discharges have been prepared for flow rates equal to that of the non-conservative pollutant under study, some reasonable approximations can be made for steady-state non-conservative pollutant concentrations without requiring additional data. Assuming a first order decay rate for the non-conservative constituent, its concentration is given by:

$$C_t = C_o e^{-kt} \tag{VI-29}$$

where

C_t = pollutant concentration at time "t"

C_o = initial pollutant concentration

k = decay rate constant

For conservative pollutants k = 0 and $C = C_o$ under steady-state conditions. Decay rates are determined empirically and depend on a large number of variables. Typical decay rates for BOD and coliform bacteria are shown in Table VI-12. If data are not available for a particular estuary, the use of these average values will provide estimates.

TABLE VI-12

TYPICAL VALUES FOR DECAY REACTION RATES 'k'*

Source	BOD	Coliform
Dyer, 1973		.578
Ketchem, 1955		.767
Chen and Orlob, 1975	.1	.5
Hydroscience, 1971	.05-.125	1-2
McGaughhey, 1968	.09	
Harleman, 1971	.069	

*k values for all reactions given on a per tidal cycle basis, 20°C.

It should be noted that decay rates are dependent upon temperature. The values given assume a temperature of 20^0C. Variations in k values for differing temperatures are given by Equation VI-30:

$$k_T = k_{20°} \Theta^{T-20°} \qquad \text{(VI-30)}$$

where

k_T = decay rate at temperature T

k_{20} = decay rate at 20^0C (as given in Table VI-12)

and

Θ = a constant (normally between 1.03 and 1.05).

Thus an ambient temperature of 10^0C would reduce a k value of 0.1 per tidal cycle to 0.074 for a $\Theta = 1.03$.

Decay effects can be compared to flushing effects by setting time equal to the flushing time and comparing the resulting decay to the known pollutant removal rate as a result of flushing. If kt in Equation VI-29 is less than 0.5 for $t = T_f$, decay processes reduce concentration by only about one-third over the flushing time. Here mixing and advective effects dominate and non-conservative decay plays a minor role. When $kT_f > 12$ decay effects reduce a batch pollutant to 5 percent of its original concentration in less than one-fourth of the flushing time. In this case, decay processes are of paramount importance in determining steady-state concentrations. Between these extremes, both processes are active in removing a pollutant from the estuary with $3 < kT_f < 4$ being the range for approximately equal contributions to removal. Dyer (1973) analyzed the situation for which decay and tidal exchange are of equal magnitude for each estuarine segment. Knowing the conservative concentration, the non-conservative steady-state concentration in a segment is given by:

$$C_i = C_o \prod_{i=1,\ldots,n} \frac{f_i}{f_o} \left(\frac{r_i}{1-(1-r_i)e^{-kt}} \right) \text{ for segments downstream of the outfall} \qquad \text{(VI-31)}$$

and

$$C_i = C_o \prod_{i=1,\ldots,n} \frac{S_i}{S_o} \left(\frac{r_i}{1-(1-r_i)e^{-kt}} \right) \text{ for segments upstream of the outfall} \qquad \text{(VI-32)}$$

where

C_i = non-conservative constituent mean concentration in segment "i"

C_o = conservative constituent mean concentration in segment of discharge

r_i = the exchange ratio for segment "i" as defined by the modified tidal prism method

n = number of segments away from the outfall (i.e. n=1 for segments adjacent to the outfall; n=2 for segments next to these segments, etc.)

and other parameters are as previously defined.

In the case of a non-conservative pollutant entering from the river, n = 1, and the only concentration expression necessary is

$$C_i = C_{i-1} \frac{f_i}{f_{i-1}} B_i \qquad \text{(VI-33)}$$

where

$$B_i = \frac{r_i}{1-(1-r_i)e^{-kt}} \qquad \text{(VI-34)}$$

Table VI-13 shows a suggested format for tabulating pollution concentrations by the modified tidal prism method.

EXAMPLE VI-7

Continuous Discharge of a Non-Conservative Pollutant into the Head of an Estuary

The Fox Mill Run Estuary (see Example VI-3) is downstream of the Gloucester, Virginia, sewage treatment plant. Knowing the discharge rate of CBOD in the plant effluent, the purpose of this example is to determine the concentration of CBOD throughout the estuary.

It is first necessary to determine the concentration of CBOD in Fox Mill Run as it enters the estuary (assume no CBOD decay within the river). The following information has been collected:

C_r, Background CBOD in river = 3 mg/l
Q_r, River flow below treatment plant discharge = 0.031 m^3/sec
Q_d, Treatment plant discharge rate = 0.006 m^3/sec
C_d, Treatment plant effluent CBOD = 45 mg/l

The CBOD concentration in the river downstream of the treatment plant is found using the equation:

$$C = \frac{C_r(Q_r - Q_d) + C_d Q_d}{Q_r}$$

or

$$C = \frac{3 \text{ mg/l}(.031-.006 \text{ m}^3\text{/sec}) + 45 \text{ mg/l}(0.006 \text{ m}^3\text{/sec})}{0.031 \text{ m}^3\text{/sec}}$$

$$C = 11.1 \text{ mg/l}$$

TABLE VI-13

SAMPLE CALCULATION TABLE FOR DISTRIBUTION OF A LOCALLY DISCHARGED NON-CONSERVATIVE POLLUTANT BY THE MODIFIED TIDAL PRISM METHOD

From Table VI-6			Mean Salinity (from salinity plot) S_i ppt	Fraction of River Water $f_i = \frac{S_s - S_i}{S_s}$	B_i	Pollutant Concentration $C=C_{i-1}\frac{f_i}{f_{i-1}} \leftarrow B_i$ (mg/l)
Segment Number	Distance of Center Above Mouth (m)	Segment Exchange Ratio r_i				

← Down Estuary

To find the CBOD concentration distribution in the estuary, the following additional data are used:

S_s, Chesapeake Bay salinity = 19.0 $^o/oo$ (at the mouth of Fox Mill Run Estuary)

k, CBOD decay constant = 0.3/day

T, Tidal cycle = 12.4 hours

so

$$kt = 0.3/\text{day} \times 12.4 \text{ hr} \times 1 \text{ day}/24 \text{ hours} = 0.155$$

Also necessary are mean salinity values for each estuary segment. Values for the Fox Mill Run Estuary are summarized in Table VI-14. Fraction of freshwater values for each segment are found using the formula:

$$f_i = \frac{S_s - S_i}{S_s}$$

where the variables are as previously defined.

Next, values of the coefficient B_i must be calculated for each segment "i". For segment 0,

r_0, the segment exchange ratio, = 0.74

and

$$B_0 = \frac{r_0}{1-(1-r_0)e^{-kt}} = \frac{0.74}{1-(1-0.74)e^{-0.155}} = 0.95$$

Coefficient values for all segments are compiled in Table VI-14.

TABLE VI-14

SALINITY AND CBOD CALCULATIONS FOR FOX MILL RUN ESTUARY

From Problem VI-3						
Segment Number	Center Point Distance Above Est. Mouth, Meters	Exchange Ratio For Segment r_i	Mean Segment Salinity S_i, ppt (From Sal. Plot)	Fraction of Fresh (River) $f_i = \frac{S_s - S_i}{S_s}$ ($S_s = 19.0$)	B_i	Concentration of $CBOD_u$ $C_i = C_{i-1} \frac{f_i}{f_{i-1}} B_i$ (mg/l)
River	(>3200)	-	~0	1.00	-	11.1
0	2950	0.74	4.7	0.75	0.95	8.1
1	2470	0.71	8.6	0.55	0.94	5.5
2	1945	0.56	11.6	0.39	0.90	3.6
3	915	0.71	15.3	0.19	0.94	1.6

Finally, CBOD concentrations for the individual segment are calculated, beginning with the uppermost segment and working downstream. The concentration in segment "i" is found by:

$$C_i = C_{i-1} \frac{f_i}{f_{i-1}} B_i$$

For segment 0, the river is taken as segment "i-1", and the calculation is as follows:

$$C_0 = 11.13 \text{ mg/l} \left(\frac{.75}{1.0}\right) 0.95 = 8.1 \text{ mg/l}$$

For segment 1,

$$C_1 = 8.1 \text{ mg/l} \left(\frac{.55}{.75}\right) 0.94 = 5.6 \text{ mg/l}$$

and so on.

Figure VI-21 depicts this estimate of the distribution of CBOD in the estuary. In addition, hypothetical concentrations of a conservative pollutant (k = 0) and coliform bacteria (k = 1.0) are plotted. Downstream concentration diminishes faster for substances having larger decay constants, as might be expected.

END OF EXAMPLE VI-7

6.4.4 Multiple Waste Load Parameter Analysis

The preceding analysis allowed calculation of the longitudinal distribution of a pollutant, either conservative or non-conservative, resulting from a single waste discharge. However, the planner will probably want to simultaneously assess both conservative and non-conservative elements from several separate discharges. This can be accomplished by graphing all desired single element distributions on one graph showing concentration

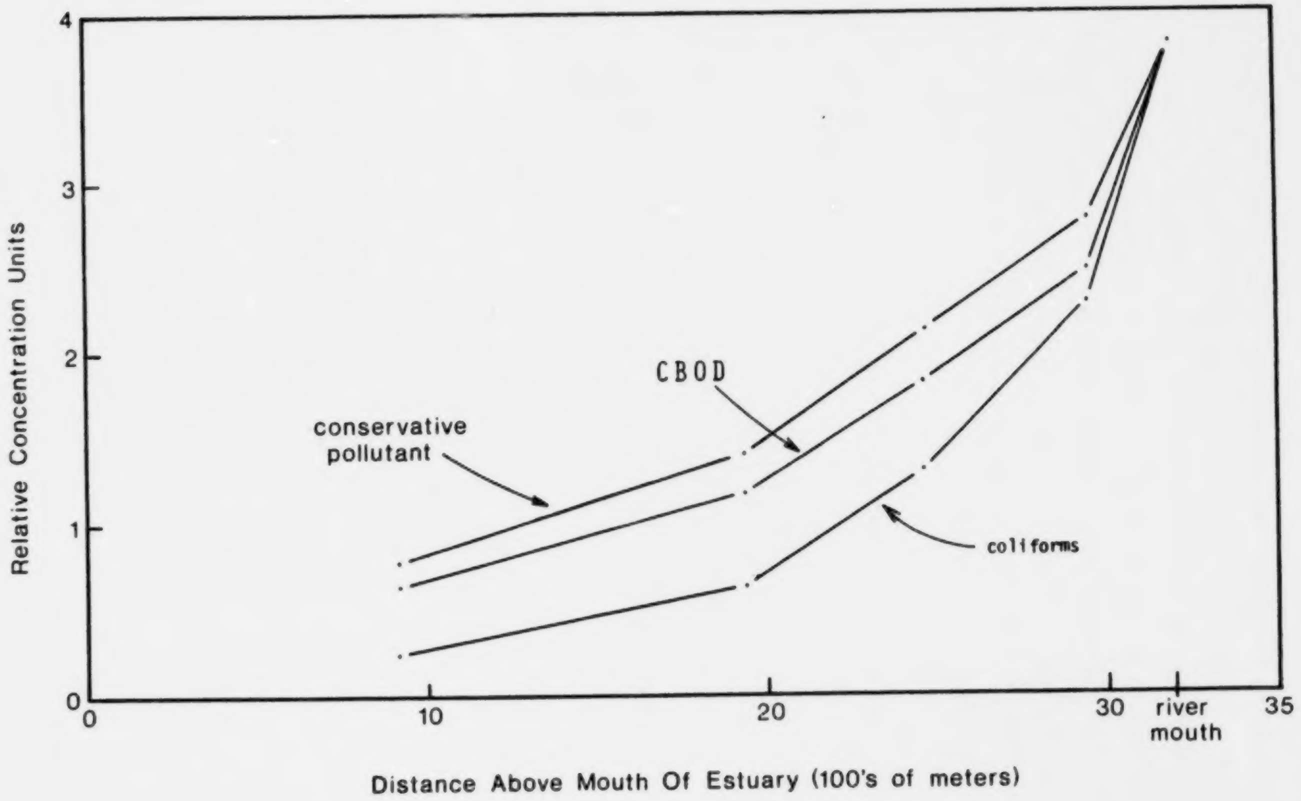


FIGURE VI-21 RELATIVE DEPLETIONS OF THREE POLLUTANTS ENTERING THE FOX MILL RUN ESTUARY, VIRGINIA

versus length of the estuary. Once graphed, the resulting concentration may be linearly added to obtain a total waste load.

The pollutant concentration increment from each source is calculated by assuming the source is the sole contribution of pollution (i.e. other waste loadings are temporarily set equal to zero). This method, called superposition, is valid as the long as volumetric discharge from any of the sources does not signicantly influence the salinity distribution within the estuary. This assumption is typically true, unless the estuary is extremely small and poorly flushed, and the volumetric discharge is large relative to tidal and advective flushing components.

An example of the superposition procedure is shown in Figure VI-22. Three local point sources of pollutants discharge at locations A, B, and C. A background source enters the estuary with the river discharge. The contribution due to each source can be found from the fraction of freshwater method (assuming the pollutants act conservatively) as follows:

$$C_b = \frac{W_R}{R} f_x \quad , \ x > 0, \text{ where } x \text{ is measured from the head of the estuary}$$

$$C_A = \begin{cases} \frac{W_A}{R} f_x \ , & x > A \\ \frac{W_A}{R} f_A \frac{S_X}{S_A} \ , & x < A \end{cases}$$

$$C_B = \begin{cases} \frac{W_B}{R} f_x \ , & x > B \\ \frac{W_B}{R} f_B \frac{S_X}{R} \ , & x < B \end{cases}$$

$$C_C = \begin{cases} \frac{W_C}{R} f_x \ , & x > C \\ \frac{W_C}{R} f_C \frac{S_X}{R} \ , & x < C \end{cases}$$

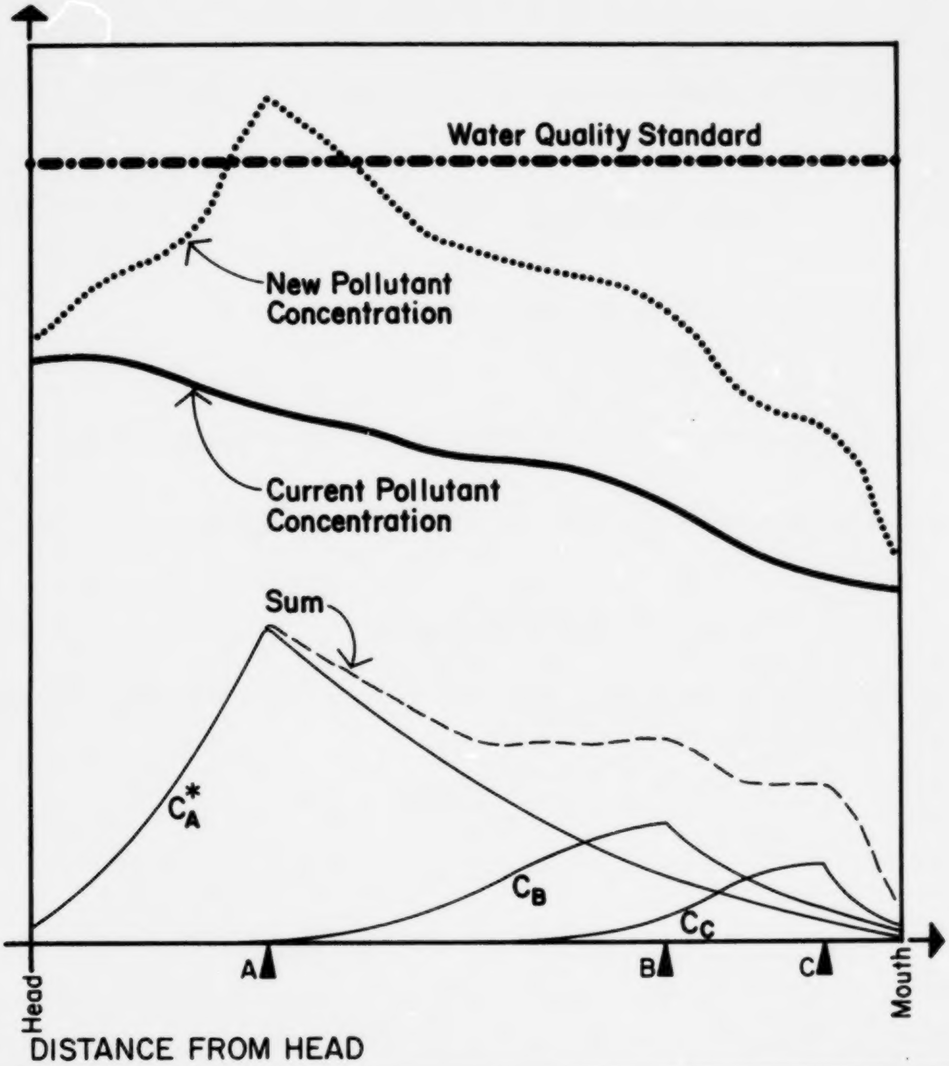


FIGURE VI-22 ADDITIVE EFFECT OF MULTIPLE WASTE LOAD ADDITIONS

where

C_b = concentration due to river discharge

C_A, C_B, C_C = concentrations due to sources A, B, and C, respectively

R = river flow rate

f_A, f_B, f_C = fraction of freshwater at locations A, B, C, respectively

S_A, S_B, S_C = salinity at locations A, B, and C, respectively.

The pollutant concentration (above background) at any location in the estuary is:

$$\text{Sum} = C_A + C_B + C_C$$

and is shown in Figure VI-22. When this is added to the background level, the total pollutant concentration becomes:

$$C_T = (C_A + C_B + C_C) + C_b$$

The dotted line in Figure VI-22 depicts C_T.

The technique of graphing outfall location and characteristics with resulting estuarine pollutant concentration can be done for all anticipated discharges. This will provide the planner with a good perspective on the source of potential water quality problems.

Where the same segmentation scheme has been used to define incremental pollutant distributions resulting from several sources, the results need not even be plotted to determine the total resultant concentrations. In this case, the estuary is evaluated on a segment-by-segment basis. The total pollutant concentration in each segment is calculated as the arithmetic sum of the concentration increments resulting from the various sources.

EXAMPLE VI-8

The previous two example problems involved calculations of nitrogen concentration in the Patuxent Estuary resulting from individual nitrogen sources. The objective of this example is to find the total nitrogen concentration in the estuary resulting from both nitrogen sources.

The eight-segment scheme of Examples VI-6 and VI-7 is retained for this problem. For each segment, the incremental nitrogen increases are summed to give the total concentration:

$$C = C_b + C_A$$

where

C_b is the concentration resulting from the N source discharging into the estuary at point A

For segment 1, the calculation is:

$$\begin{aligned} C &= 1.75 \text{ mg/l (from river)} + 0.43 \text{ mg/l (from local source)} \\ &= 2.18 \text{ mg/l total nitrogen} \end{aligned}$$

Necessary data and final concentrations for each segment are shown in Table VI-15.

END OF EXAMPLE VI-8

6.4.5 Dispersion-Advection Equations for Predicting Pollutant Distributions

Dispersion-advection equations offer an attractive method, at least theoretically, of predicting pollutant and dissolved oxygen concentrations in estuaries. However, from the point of view of hand calculation, the advection-dispersion equations are usually tedious to solve, and therefore mistakes can unknowingly be incorporated into the calculations.

Dispersion-advection equations have been developed in a variety of forms, including one-, two-, and three-dimensional representations. The equations in this section are limited to one-dimensional representations in

TABLE VI-15

DISTRIBUTION OF TOTAL NITROGEN IN THE PATUXENT ESTUARY DUE TO TWO SOURCES OF NITROGEN

Segment Number	Results From Problem VI-4 Total Nitrogen From River mgN/l, C_b	Results From Problem VI-5 Total Nitrogen From Point A Source (Segment 4) mgN/l, C_A	Resultant Concentration $C=C_b + C_A$ mgN/l
8	0.07	0.25	0.32
7	0.21	0.74	0.95
6	0.36	1.26	1.62
5	0.55	1.93	2.48
4	0.80	3.06	3.92
3	1.30	1.74	3.04
2	1.56	0.95	2.51
1	1.75	0.43	2.18
River	1.88	0.00	1.88

order to reduce the amount of data and calculations required.

One-dimensional dispersion-advection equations can be expressed in quite divergent forms, depending on boundary conditions, cross-sectional area variation over distance, and source-sink terms. O'Connor (1965), for example, developed a variety of one-dimensional advection-dispersion equations for pollutant and dissolved oxygen analyses in estuaries, some of which are infeasible for use on the hand-calculation level.

The advection-dispersion equations to be presented subsequently in this chapter can be used to predict:

- distributions of conservative or non-conservative pollutants,
- pollutant distributions in embayments, and
- dissolved oxygen concentrations.

Solutions from advection-dispersion can be superposed to account for multiple discharges. Example VI-9, to be presented subsequently, will illustrate this process.

As the name of the equations implies, dispersion coefficients are needed in order to solve advection-dispersion equations. Tidally averaged dispersion coefficients are required for the steady-state formulations used here. The tidally averaged dispersion coefficient (E_L) can be estimated from the following expression:

$$E_L = \frac{RS}{A\ dS/dx} \qquad \text{(VI-35)}$$

$$\approx \frac{2RS\Delta x}{A(S_{x+\Delta x} - S_{x-\Delta x})} \qquad \text{(VI-36)}$$

where

S = tidally and cross sectionally averaged salinity in vicinity of discharge

$2\Delta x$ = distance between the salinity measurements $S_{x+\Delta x}$ (at a distance Δx down estuary) and $S_{x-\Delta x}$ (at a distance Δx up estuary)

R = freshwater flow rate in vicinity of discharge

The distance interval $2\Delta x$ should be chosen so that no tributaries are contained within the interval.

In the absence of site specific data, the dispersion coefficients shown in Tables VI-16 and VI-17 can provide estimates of dispersion coefficients.

For pollutants which decay according to first order decay kinetics, the steady state mass balance equation describing their distribution is:

$$E_L \frac{d^2C}{dx^2} - \frac{U\,dC}{dx} - kC = 0 \qquad \text{(VI-37)}$$

The solution to Equation VI-37 is:

$$C = \begin{cases} C_o\, e^{\,j_2 x} & x > 0 \text{ (down estuary)} \qquad \text{(VI-38a)} \\ C_o e^{\,j_1 x} & x < 0 \text{ (up estuary)} \qquad \text{(VI-38b)} \end{cases}$$

where

$$j_2 = \frac{R}{2AE_L}\left(1 - \sqrt{1 + \frac{4kE_L A^2}{R^2}}\right)$$

$$j_1 = \frac{R}{2AE_L}\left(1 + \sqrt{1 + \frac{4kE_L A^2}{R^2}}\right)$$

TABLE VI-16

TIDALLY AVERAGED DISPERSION COEFFICIENTS FOR SELECTED ESTUARIES (FROM HYDROSCIENCE, 1971)

Estuary	Freshwater Inflow (cfs)	Low Flow Net Nontidal Velocity (fps) Head - Mouth	Dispersion Coefficient (mi^2/day*)
Delaware River	2,500	0.12-0.009	5
Hudson River (N.Y.)	5,000	0.037	20
East River (N.Y.)	0	0.0	10
Cooper River (S.C.)	10,000	0.25	30
Savannah R. (Ga., S.C.)	7,000	0.7-0.17	10-20
Lower Raritan R. (N.J.)	150	0.047-0.029	5
South River (N.J.)	23	0.01	5
Houston Ship Channel (Texas)	900	0.05	27
Cape Fear River (N.C.)	1,000	0.48-0.03	2-10
Potomac River (Va.)	550	0.006-0.0003	1-10
Compton Creek (N.J.)	10	0.01-0.013	1
Wappinger and Fishkill Creek (N.Y.)	2	0.004-0.001	0.5-1

*1 mi^2/day = 322.67 ft^2/sec

TABLE VI-17

TIDALLY AVERAGED DISPERSION COEFFICIENTS
(FROM OFFICER, 1976)

Estuary	Dispersion Coefficient Range (ft^2/sec)	Comments
San Francisco Bay Southern Arm Northern Arm	 200-2,000 500-20,000	Measurements were made at slack water over a period of one to a few days. The fraction of freshwater method was used. Measurements were taken over three tidal cycles at 25 locations.
Hudson River	4,800-16,000	The dispersion coefficient was derived by assuming E_L to be constant for the reach studied, and that it varied only with flow. A good relationship resulted between E_L and flow, substantiating the assumption.
Narrows of Mercey	1,430-4,000	The fraction of freshwater method was used by taking mean values of salinity over a tidal cycle at different cross sections.
Potomac River	65-650	The dispersion coefficient was found to be a function of distance below the Chain Bridge. Both salinity distribution studies (using the fraction of freshwater method) and dye release studies were used to determine E_L.
Severn Estuary	75-750 (by Stommel) 580-1,870 (Bowden)	Bowden recalculated $_L$ values originally determined by Stommel, who had used the fraction of freshwater method. Bowden included the freshwater inflows from tributaries, which produced the larger estimates of E_L.

TABLE VI-17 (continued)

Estuary	Dispersion Coefficient Range (ft^2/sec)	Comments
Tay Estuary	530-1,600 (up estuary) 1,600-7,500 (down estuary)	The fraction of freshwater method was used. At a given location, E_L was found to vary with freshwater inflow rate.
Thames Estuary	600-1,000 (low flow) 3,600 (high flow)	Calculations were performed using the fraction of freshwater method, between 10 and 30 miles below London Bridge.
Yaquina Estuary	650-9,200 (high flow) 140-1,060 (low flow)	The dispersion coefficients for high flow conditions were substantially higher than for low flow conditions, at the same locations. The fraction of freshwater method was used.

U = net velocity

k = decay rate

W = discharge rate of pollutant (at x=0)

For Equations VI-38a and VI-38b to accurately estimate the pollutant distribution in an estuary, the cross-sectional area of the estuary should be fairly constant over distance, and the estuary should be relatively long. For screening purposes the first constraint can be met by choosing a cross-sectional area representative of the length of estuary being investigated. If the estuary is very short, however, pollutants might be washed out of the estuary fast enough to prevent attainment of a steady-state distribution assumed by Equations VI-38a and VI-38b. For shorter estuaries the fraction of freshwater method, modified tidal prism method, or near field approach are more appropriate.

At times when the freshwater flow rate in an estuary is essentially zero pollutant concentrations might increase to substantial levels, if tidal flushing is small. Under these conditions the mass-balance expression for a pollutant obeying first order kinetics is:

$$E_L \frac{d^2C}{dx^2} - kc = 0 \qquad \text{(VI-39)}$$

The solution to this equation is:

$$C = \begin{cases} C_o \exp\left(-\sqrt{\frac{k}{E_L}}\ x\right) & \text{for } x > 0 \text{ (down estuary)} \qquad \text{(VI-40a)} \\ C_o \exp\left(\sqrt{\frac{k}{E_L}}\ x\right) & \text{for } x < 0 \text{ (up estuary)} \qquad \text{(VI-40b)} \end{cases}$$

where

$$C_o = \frac{W}{A\sqrt{4kE_L}} \qquad \text{(VI-41)}$$

When the pollutant is conservative (i.e. k=0), Equation (VI-39) reduces to:

$$E_L \frac{d^2C}{dx^2} = 0 \qquad \text{(VI-42)}$$

The solution is:

$$C = \begin{cases} C_o \ , \ x < 0 \text{ (up estuary)} & \text{(VI-43a)} \\ \dfrac{W}{E_L A}(L-x) + C_L \ , \ x > 0 \text{ (down estuary)} & \text{(VI-43b)} \end{cases}$$

where

$C_o = C_L + \dfrac{WL}{E_L A}$

C_L = background concentration of the pollutant at the mouth of the estuary

L = distance from the discharge location to the mouth of the estuary.

Equation VI-43 illustrates the important concept that the concentrations of conservative pollutants are constant up estuary from the discharge location (when the river discharge is negligible) and decrease linearly from the discharge point to the mouth of the estuary. Equations VI-40 and VI-43 apply to estuaries of constant, or approximately constant, cross-sectional area (e.g. sloughs). If the cross-sectional area increases rapidly with distance toward the mouth, the methods presented in Section 6.5 are more appropriate.

The dissolved oxygen deficit equation (where deficit is defined as the difference between the saturation concentration and the actual dissolved oxygen concentration) for one-dimensional estuaries at steady-state conditions is:

$$\frac{UdD}{dx} = E_L \frac{d^2D}{dx^2} - k_2D + kL \qquad \text{(VI-44)}$$

where

D = dissolved oxygen deficit

L = BOD concentration

k_2 = reaeration rate

k = BOD decay rate

Using Equation VI-38 to represent the BOD distribution, the expression for the deficit D is:

$$D = \frac{kW}{A(k_2-k)}\left[\frac{1}{\sqrt{a_1}}\exp\left(\frac{U \pm \sqrt{a_1}}{2E_L}x\right) - \frac{1}{\sqrt{a_2}}\exp\left(\frac{U \pm \sqrt{a_2}}{2E_L}x\right)\right] - \frac{M}{A\sqrt{a_2}}\exp\left(\frac{U \pm \sqrt{a_2}}{2E_L}x\right) \qquad \text{(VI-45)}$$

where

The plus (+) sign is used to predict concentrations up estuary $(x<0)$

The minus (-) sign is used to predict concentrations down estuary $(x>0)$

$a_1 = U^2 + 4kE_L$

$a_2 = U^2 + 4k_2E_L$

M = mass flux of dissolved oxygen contained in the discharge

The advantage of expressing the dissolved oxygen concentration in terms of the deficit is that the principle of superposition can be invoked for multiple discharges within a single estuary. Specifically

$$D = \Sigma D_i \qquad \text{(VI-46)}$$

and

$$C = C_s - \Sigma D_i \qquad \text{(VI-47)}$$

where

D_i = dissolved oxygen deficit resulting from the i^th^ discharge

C = final dissolved oxygen concentration

C_s = dissolved oxygen saturation level.

Figure VI-23 shows the relationship between dissolved oxygen saturation and temperature and salinity.

EXAMPLE VI-9

Dissolved Oxygen Concentration Resulting from Two Sources of BOD

Two municipal wastewater treatment plants discharge significant quantities of BOD into the James River in Virginia. One discharges near Hopewell, and the second 10 miles further down estuary, near West Point. Calculate the dissolved oxygen concentration in the estuary as a function of distance. Pertinent data are:

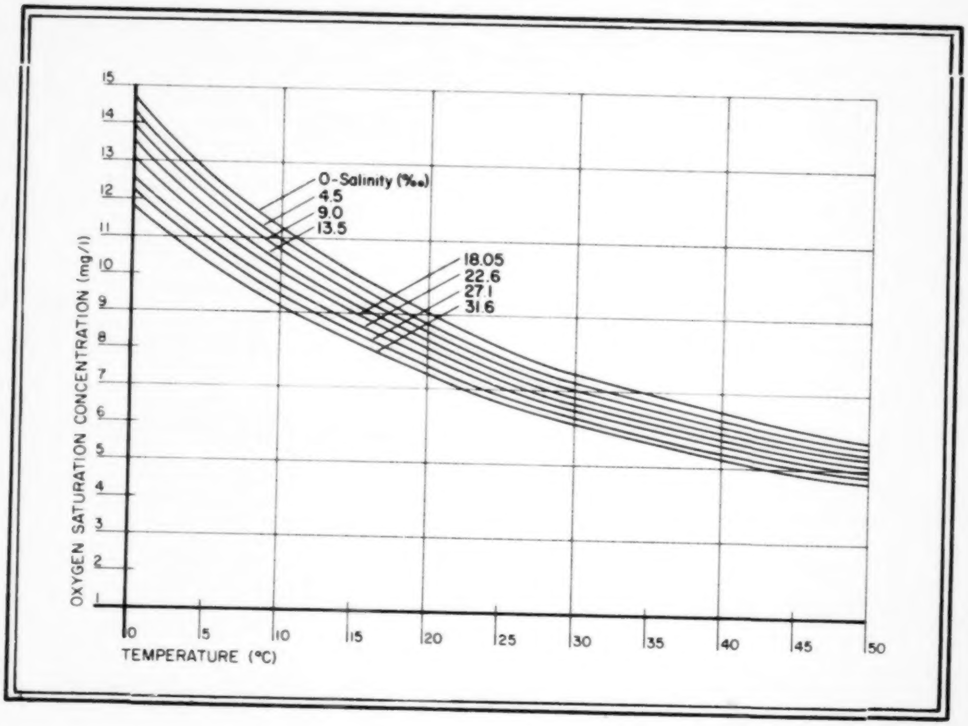


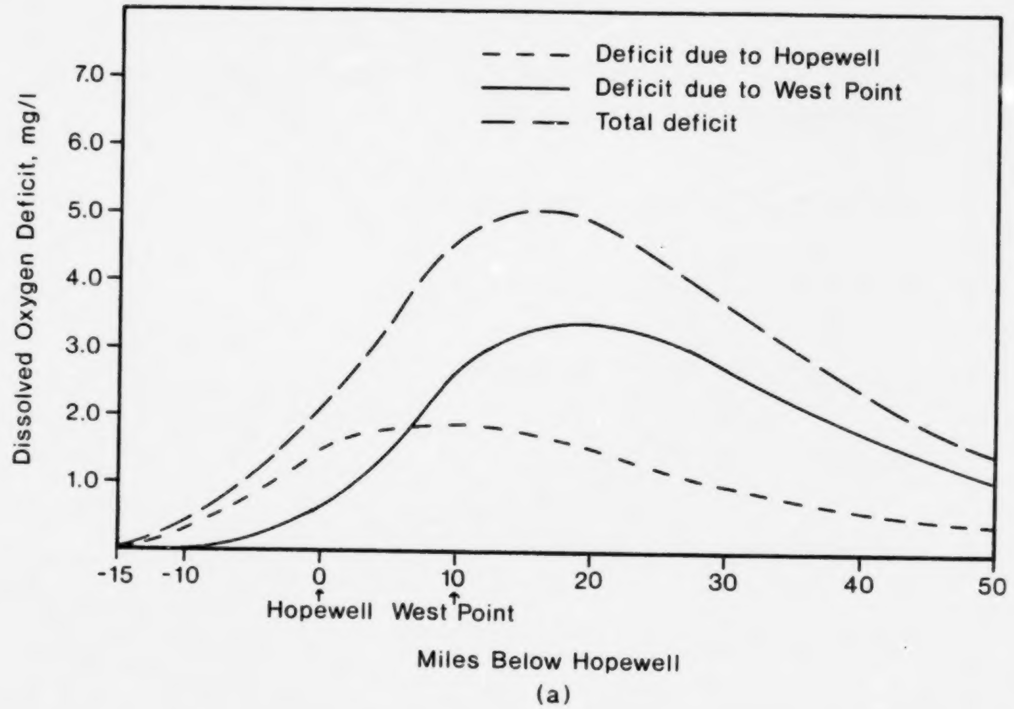
FIGURE VI-23 DISSOLVED OXYGEN SATURATION AS A FUNCTION OF TEMPERATURE AND SALINITY

- BOD_5 in Hopewell plant effluent = 69,000 lbs/day
- BOD in West Point plant effluent, located 10 miles downstream from Hopewell = 175,000 lbs/day
- freshwater flow rate = 2,900 cfs
- dissolved oxygen saturation = 8.2 mg/l
- cross sectional area = 20,000 ft^2
- reaeration rate = 0.2/day
- deoxygenation rate = 0.3/day
- dispersion coefficient = 12.5 mi^2/day
- effluent dissolved oxygen = 0.0 mg/l.

The dissolved oxygen deficit due to each of the two contributions can be determined independently of the other using Equation IV-45. The results are plotted in Figure VI-24. The deficits are added to produce the total deficit (D(x)) due to both discharges (Figure VI-24a). The distance scale in Figure VI-24a is referenced to the Hopewell plant. The West Point plant is placed at mile 10. When the deficit at this location due to the West Point plant is calculated, set x = 0 in Equation VI-45. The dissolved oxygen concentration then becomes C(x) = 8.2-D(x), and is shown in Figure VI-24b.

One example calculation of dissolved oxygen deficit will be shown to illustrate the process. Consider the deficit produced at mile 0.0, due to the Hopewell plant. The waste loading from the Hopewell plant is:

$$69{,}000 \times 1.46 = 100{,}000 \text{ lbs/day, BOD-ultimate} = 1.16 \text{ lbs/sec}$$



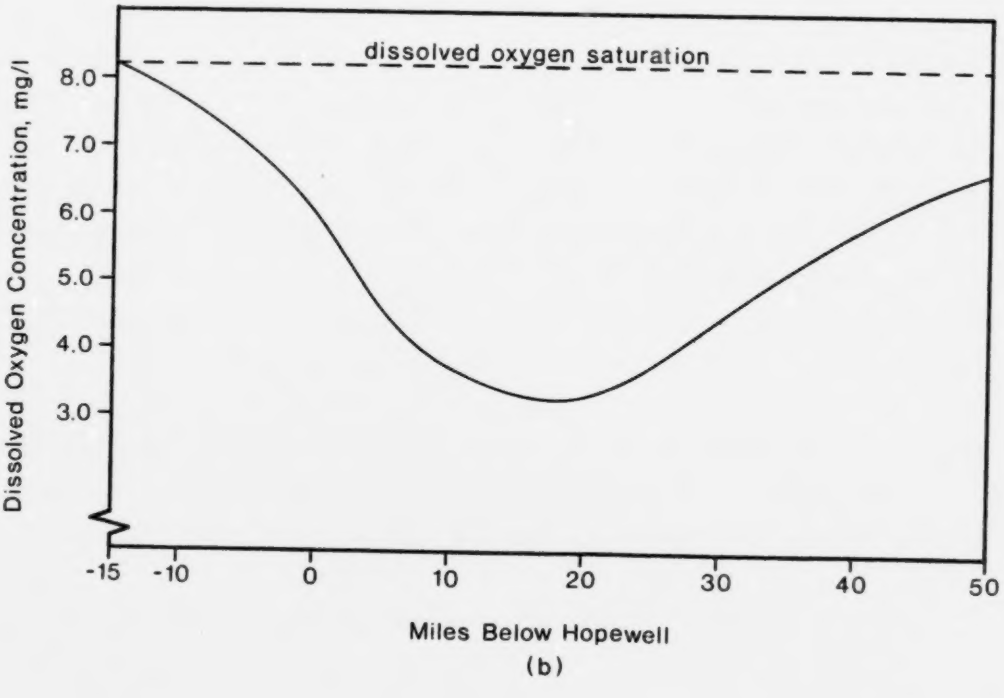


FIGURE VI-24 PREDICTED DISSOLVED OXYGEN PROFILE IN JAMES RIVER

When

x = 0 Equation VI-45 simplifies to:

$$D = \frac{kW}{A(k_2-k)}\left(\frac{1}{\sqrt{a_1}} - \frac{1}{\sqrt{a_2}}\right)$$

$$a_1 = U^2 + 4k_1E_L\left(\frac{2900}{0000}\right)^2 + \frac{4(.3)(12.5)(5280)(5280)}{81400 \cdot 86400} = .077\ \frac{ft^2}{sec^2}$$

so

$$\sqrt{a_1} = .278 \text{ ft/sec}$$

$$a_2 = U^2 + 4k_2E_L = 0.058 \text{ ft}^2/\text{sec}^2$$

so

$$\sqrt{a_2} = .242 \text{ ft/sec}$$

The deficit is:

$$D = \frac{(.3)(1.16)}{20000(.2-.3)}\left[\frac{1}{.278} - \frac{1}{.242}\right] = 9.3 \times 10^{-5} \text{ lb/ft}^3 = 1.5 \text{ mg/l}$$

This value is then plotted in Figure VI-24 at mile point 0.0. The deficit at this location due to West Point is evaluated at x = -10 miles in Equation VI-45, since West Point is located 10 miles down estuary of Hopewell. A deficit of 0.6 mg/l is found, and is plotted in Figure VI-24 at mile point 0.0. The total deficit at Hopewell is 1.5 +0.6 = 2.1 mg/l, as shown in the figure.

END OF EXAMPLE VI-9

6.4.6 Pritchard's Two-dimensional Box Model for Stratified Estuaries

Many estuaries in the United States are either stratified or partially mixed. Because the circulation of stratified systems is fairly complex, few hand calculation methods are available for their analysis. Instead computerized solutions are generally used.

One method developed by Pritchard (1969) which predicts the distribution of pollutants in partially mixed or stratified estuaries is suitable for hand calculations provided the user does not require too much spatial resolution. This method, called the "two-dimensional box model", divides the estuary horizontally from head to mouth into a series of longitudinal segments. Each segment is divided into a surface layer and a bottom layer. The analysis results in a system of n simultaneous linear equations with n unknowns, where n equals twice the number of horizontal segments. The unknowns are the pollutant concentrations in each layer.

Division of the estuary into only two horizontal segments results in four simultaneous equations, which is probably the most one would like to solve entirely by hand. However, many programmable hand calculators contain library routines for solving systems of 10 or more simultaneous equations, which would allow the estuary to be divided into 5 or more horizontal segments. If many more segments are desired, the solution could be easily implemented on a computer using a numerical technique such as Gaussian elimination to solve the resulting system of simultaneous linear equations.

The following information is required for the two-dimensional box analysis: 1) the freshwater flow rate due to the river; 2) the pollutant mass loading rates; and 3) the longitudinal salinity profiles along the length of the estuary in the upper and lower layers, and the salinity at the boundary between these two layers. The upper layer represents the portion of the water column having a net nontidal flow directed seaward, and the lower layer represents the portion of the water column having net nontidal flow directed up the estuary. If no velocity data are available, these layers can generally be estimated based on the vertical salinity profiles.

Figure VI-25 shows the parameters used in the analysis, which are defined as follows:

n = segment number, increasing from head toward mouth

$(S_u)_n$ = salinity in upper layer of segment n

$(S_l)_n$ = salinity in lower layer of segment n

$(S_v)_n$ = salinity at the boundary between the upper and lower layers of segment n

$(S_u)_{n-1,\ n}$ = salinity in the upper layer at the boundary between segments n-1 and n

$(S_l)_{n-1,\ n}$ = salinity in the lower layer at the boundary between segments n-1 and n

$(Q_u)_{n-1,\ n}$ = net nontidal flow rate in the upper layer from segment n-1 to n

$(Q_l)_{n,\ n-1}$ = net nontidal flow rate in the lower layer from segment n to n-1

$(Q_v)_n$ = net upward vertical flow from the lower to the upper layer of segment n

E_n = vertical exchange coefficient between the lower and upper layers of segment n

R = freshwater flow rate due to river

$(q_u)_n$ = pollutant mass loading rate to upper layer of segment n (from external sources)

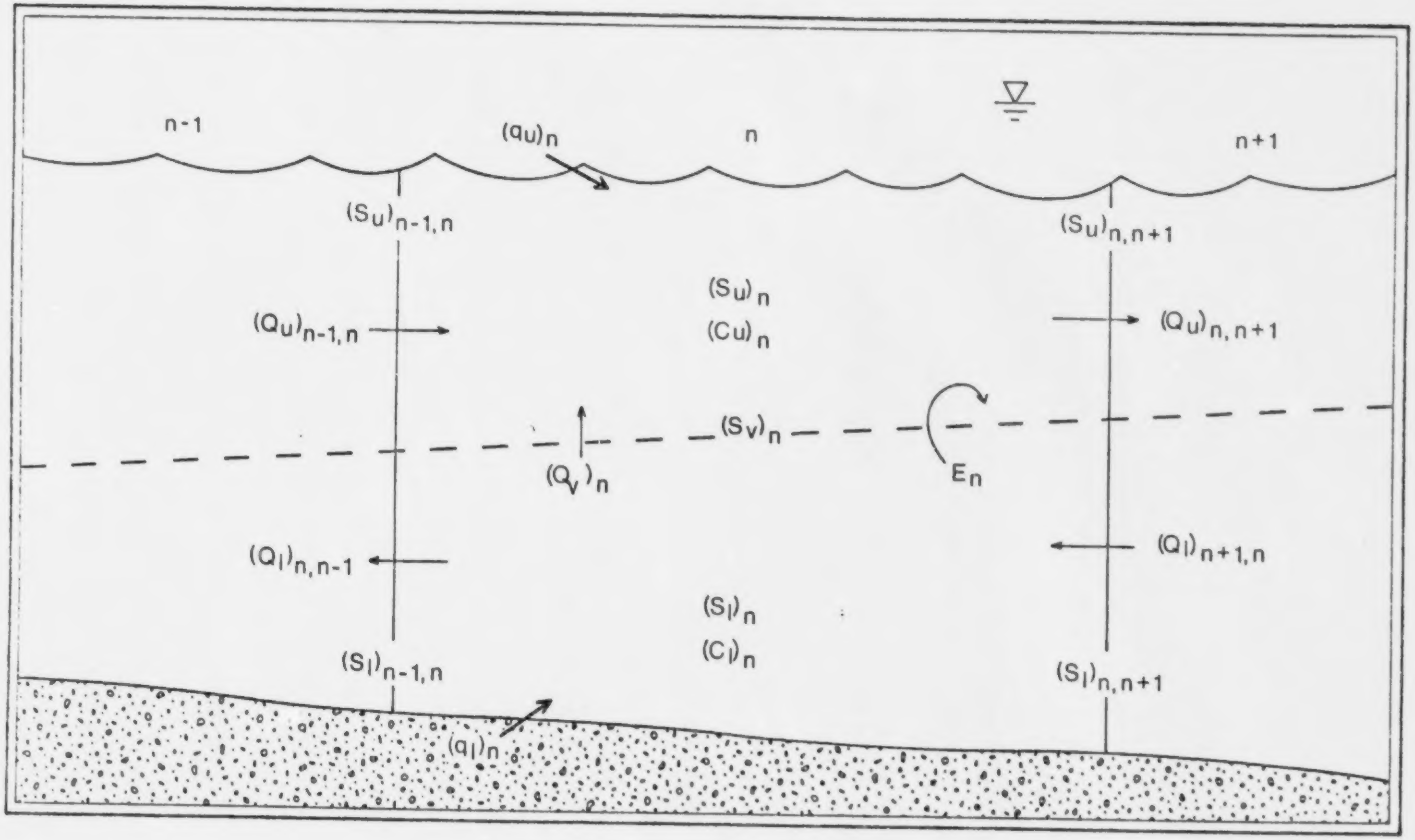


FIGURE VI-25 DEFINITION SKETCH FOR PRITCHARD'S TWO-DIMENSIONAL BOX MODEL

$(q_l)_n$ = pollutant mass loading rate to lower layer of segment n (from external sources)

$(C_u)_n$ = pollutant concentration in the upper layer of segment n

$(C_l)_n$ = pollutant concentration in the lower layer of segment n

Pritchard's two-dimensional box analysis as presented here requires the following assumptions:

1. steady-state salinity distribution
2. the pollutant is conservative
3. the concentration of the pollutant is uniform within each layer of each segment and
4. the pollutant concentration at the boundary between segments or layers is equal to the average of the concentrations in the two adjacent segments or layers.

Application of the two-dimensional box model involves six steps. These are:

1. Plot the longitudinal salinity profiles in the upper and lower layers, and at the interface between the two layers. If information on the net nontidal velocity distribution is not available to define the layers, the boundary may be estimated for a given section of the estuary as the depth at which the vertical salinity gradient is maximum. The resulting plots will be used to determine the average salinities in each segment and layer, and the salinities at the boundaries between each segment and layer.

2. Segment the estuary. The number of segments will depend on the degree of spatial resolution desired, and the limitations of the hand calculators used to solve the system of simultaneous equations. The accuracy of the results will generally increase with the number of segments used, since the assumptions of the analysis are better satisfied. A minimum of three horizontal segments should probably be used to obtain even a rough estimate of the pollutant distribution in the estuary. This will require the solution of six equations and six unknowns.

3. Compute the net nontidal flows in the upper layer and lower layer at the boundary between each horizontal segment using Knudson's Hydrographical Theorem (Dyer, 1973):

$$(Q_u)_{n-1,\,n} = R \frac{(S_l)_{n-1,\,n}}{(S_l)_{n-1,\,n} - (S_u)_{n-1,\,n}} \qquad \text{(VI-48)}$$

$$(Q_l)_{n,\,n-1} = R \frac{(S_u)_{n-1,\,n}}{(S_l)_{n-1,\,n} - (S_u)_{n-1,\,n}} \qquad \text{(VI-49)}$$

At the upstream freshwater boundary of the estuary, $(Q_l)_{n,\,n-1} = 0$.

4. Compute the net upward vertical flows between layers for each segment using the continuity equation for the upper layer of the segment:

$$(Q_v)_n = (Q_u)_{n,\,n+1} - (Q_u)_{n-1,\,n} \qquad \text{(VI-50)}$$

5. Compute the vertical exchange coefficients between layers for each segment using the salinity balance equation for the upper layer of the segment, which can be arranged in the following form:

$$E_n = \frac{(Q_u)_{n,\,n+1}\,(S_u)_{n,\,n+1} - (Q_u)_{n-1,\,n}\,(S_u)_{n-1,\,n} - (Q_v)_n\,(S_v)_n}{(S_l)_n - (S_u)_n} \qquad \text{(VI-51)}$$

6. Set up and solve a system of simultaneous linear equations with one equation for each segment and layer where the pollutant concentrations are the unknowns. These equations are based on a pollutant mass balance for each segment and layer. The mass balance equations are:

$$\begin{aligned} &(Q_u)_{n-1,\,n}\left[\frac{(C_u)_{n-1} + (C_u)_n}{2}\right] + (Q_v)_n\left[\frac{(C_u)_n + (C_l)_n}{2}\right] + E_n\left[(C_l)_n - (C_u)_n\right] \\ &\qquad - (Q_u)_{n,\,n+1}\left[\frac{(C_u)_n + (C_u)_{n+1}}{2}\right] + (q_u)_n = 0 \end{aligned} \qquad \text{(VI-52)}$$

for the upper layer of segment n and

$$\begin{aligned} &(Q_l)_{n+1,\,n}\left[\frac{(C_l)_{n+1} + (C_l)_n}{2}\right] - (Q_l)_{n,\,n-1}\left[\frac{(C_l)_n + (C_l)_{n-1}}{2}\right] \\ &\qquad - (Q_v)_n\left[\frac{(C_l)_n + (C_u)_n}{2}\right] - E_n\left[(C_l)_n - (C_u)_n\right] + (q_l)_n = 0 \end{aligned} \qquad \text{(VI-53)}$$

for the lower layer of segment n.

Since most pollutant discharges are buoyant, they should be considered as loadings to the upper layer, even though they may be physically introduced at the bottom. Pollutants which are denser than the upper waters and which would sink to the bottom should be considered as loadings to the lower layer. However, the analysis is not applicable to pollutants which tend to remain near the bottom and accumulate in or react with the bottom sediments.

The above mass balance equations can be simplified and rearranged into the following form:

$$\begin{aligned}&\left[(Q_u)_{n-1,\ n}\right](C_u)_{n-1} + \left[-2E_n\right](C_u)_n + \left[2E_n + (Q_v)_n\right](C_l)_n \\ &\quad + \left[-(Q_u)_{n,\ n+1}\right](C_u)_{n+1} = -2(q_u)_n\end{aligned} \tag{VI-54}$$

for the upper layer of segment n and

$$\begin{aligned}&\left[-(Q_l)_{n,\ n-1}\right](C_l)_{n-1} + \left[2E_n - (Q_v)_n\right](C_u)_n + \left[-2E_n\right](C_l)_n \\ &\quad + \left[(Q_l)_{n+1,\ n}\right](C_l)_{n+1} = -2(q_l)_n\end{aligned} \tag{VI-55}$$

for the lower layer of segment n. This pair of equations is written for each segment, resulting in a system of simultaneous equations where the concentrations, $(C_u)_n$ and $(C_l)_n$, are the unknowns, the terms enclosed in square brackets are the coefficients, and the terms on the right hand side of the equations are the constants.

However, since each equation involves both the uptream and downstream segments for a given layer, the boundary conditions at both the upstream and downstream end of the estuary must be applied so that there will not be more unknowns than equations. At the upstream end of the estuary, the following boundary conditions apply:

$(Q_u)_{n-1,\, n} = R =$ river flow rate

$(C_u)_{n-1} = C_R =$ pollutant in river

$(Q_l)_{n,\, n-1} = 0$ (no salt water movement upstream into the river)

These conditions simplify the previous equations to

$$\left[-2E_1\right](C_u)_1 + \left[2E_1 + (Q_v)_1\right](C_l)_1 + \left[-(Q_u)_{1,2}\right](C_u)_2 - (C_u)_1 R = -2(q_u)_1 - 2RC_R \qquad \text{(VI-56)}$$

for the upper layer of the first upstream segment and

$$\left[2E_1 - (Q_v)_1\right](C_u)_1 + \left[-2E_1\right](C_l)_1 + \left[(Q_l)_{2,1}\right](C_l)_2 = -2(q_l)_1 \qquad \text{(VI-57)}$$

for the lower layer of the first upstream segment.

For the lower layer of the last downstream segment at the ocean end of the estuary, the following boundary condition is used to simplify the equation:

$(C_l)_{n+1} = 0$ (no pollutant entering the lower layer from the ocean waters outside the mouth of estuary)

which simplifies the corresponding equation to:

$$\left[-(Q_l)_{n,\, n-1}\right](C_l)_{n-1} + \left[2E_n - (Q_v)_n\right](C_u)_n + \left[-2E_n\right](C_l)_n = -2(q_l)_n \qquad \text{(VI-58)}$$

For the upper layer of the last segment at the mouth of the estuary, some assumption must be made about the pollutant concentration in the upper layer just outside the mouth to eliminate the (n+1) term from the equation. If actual data are available based on field measurements, a measured value of $(C_n)_{n+1}$ can be used. This simplifies the corresponding equation to:

$$\left[(Q_u)_{n-1,\,n}\right](C_u)_{n-1} + \left[-2E_n\right](C_u)_n + \left[2E_n + (Q_v)_n\right](C_l)_n = -2(q_u)_n + (Q_u)_{n,\,n+1}\,C_o \quad \text{(VI-59)}$$

where C_0 is the measured pollutant concentration in the surface waters outside the mouth of the estuary. If no data are available, the simplest assumption that can be made is that the concentration outside the mouth equals the concentration in the surface layer of the last segment inside the mouth, or $(C_u)_{n+1} = (C_u)_n$. Alternatively, the concentration outside the mouth may be assumed to equal some fraction of the concentration inside the mouth, or

$$(C_u)_{n+1} = f_c\,(C_u)_n$$

where f_c is the selected fraction. The previous assumption $(C_u)_{n+1} = (C_u)_n$ is one case of this second assumption where the fraction equals one ($f_c = 1$). Using the second more general assumption, the equation of the upper layer of the last downstream segment simplifies to

$$\left[(Q_u)_{n-1,\,n}\right](C_u)_{n-1} + \left[-2E_n - f_c\,(Q_u)_{n,\,n+1}\right](C_u)_n + \left[2E_n + (Q_v)_n\right](C_l)_n = -2(q_u)_n \quad \text{(VI-60)}$$

Step (6) of the two-dimensional box analysis involves computing all of the coefficients and constants in the system of equations defining each segment and layer (equations VI-54 and VI-55) and applying the boundary conditions to produce equations for the first upstream and last downstream segments in the estuary (equations VI-56 through VI-60). The coefficients and constants are functions of the variables previously computed in steps (3) through (5). The resulting equations are then solved using library routines in programmable hand calculators, or by programming an appropriate numerical technique such as Gaussian elimination on either a programmable hand calculator or a computer.

Since the analysis requires application of the boundary conditions at the freshwater head of the estuary and the coastal mouth of the estuary to obtain the same number of equations as unknowns, the entire estuary must be included in the first cut analysis. The initial analysis will yield the overall pollutant distribution throughout the entire estuary. Once this is determined, the analysis could be repeated to obtain more detail for smaller portions of the estuary by using the first cut results to estimate the pollutant boundary conditions at each end of the region of concern, and then rearranging equations (7) and (8) so the terms involving the concentrations outside the specified regions are treated as constants and moved to the right hand side of the equations.

The Pritchard Model theoretically allows external pollutant loading to be introduced directly into any segment along the estuary. By moving external loadings from the head to near the mouth of the estuary, the planner can predict how pollutant levels are affected. However, experience with the model has shown that when external side loadings are considerably larger than those which enter at the head of the estuary, model instabilities can arise. When this occurs, the pollutant profile oscillates from segment to segment, and negative concentrations can result. It is recommended that the user first run the Pritchard Model by putting all pollutant loading into the head of the estuary. This situation appears to be always stable, and, as the following example shows, reasonable pollutant profiles are predicted.

EXAMPLE VI-10

Pollutant Distribution in a Stratified Estuary

The Patuxant River in Maryland is a partially stratified estuary, where the degree of stratification depends on the freshwater flow rate discharged at the head of the estuary. Table VI-18 shows the salinity distribution within the estuary under low flow conditions for each segment and layer. The location of each layer is shown in Figure VI-26. Also shown in the table is the pollutant distribution by layer and segment for a mass flux of 125 lbs/day (57 kg/day) of

TABLE VI-18

SALINITY AND POLLUTANT DISTRIBUTION IN PATUXENT ESTUARY UNDER LOW FLOW CONDITIONS

	Salinity (as Chloride, mg/l)		Pollutant Concentration (mg/l)	
Segment Number	Upper Layer	Lower Layer	Upper Layer	Lower Layer
1	496.	524.	0.193	0.192
2	1831.	1940.	0.173	0.171
3	3771.	3970.	0.144	0.141
4	6050.	6280.	0.100	0.108
5	8040.	8220.	0.081	0.078
6	9310	9910.	0.062	0.053
7	10010.	10660.	0.051	0.042
8	10790.	11070.	0.040	0.036
9	11240.	11760.	0.033	0.025
10	11830.	12120.	0.025.	0.020
11	12100.	12650.	0.021	0.013
12	12750.	12850.	0.011	0.009
boundary	13500.	13500.	0.0	0.0

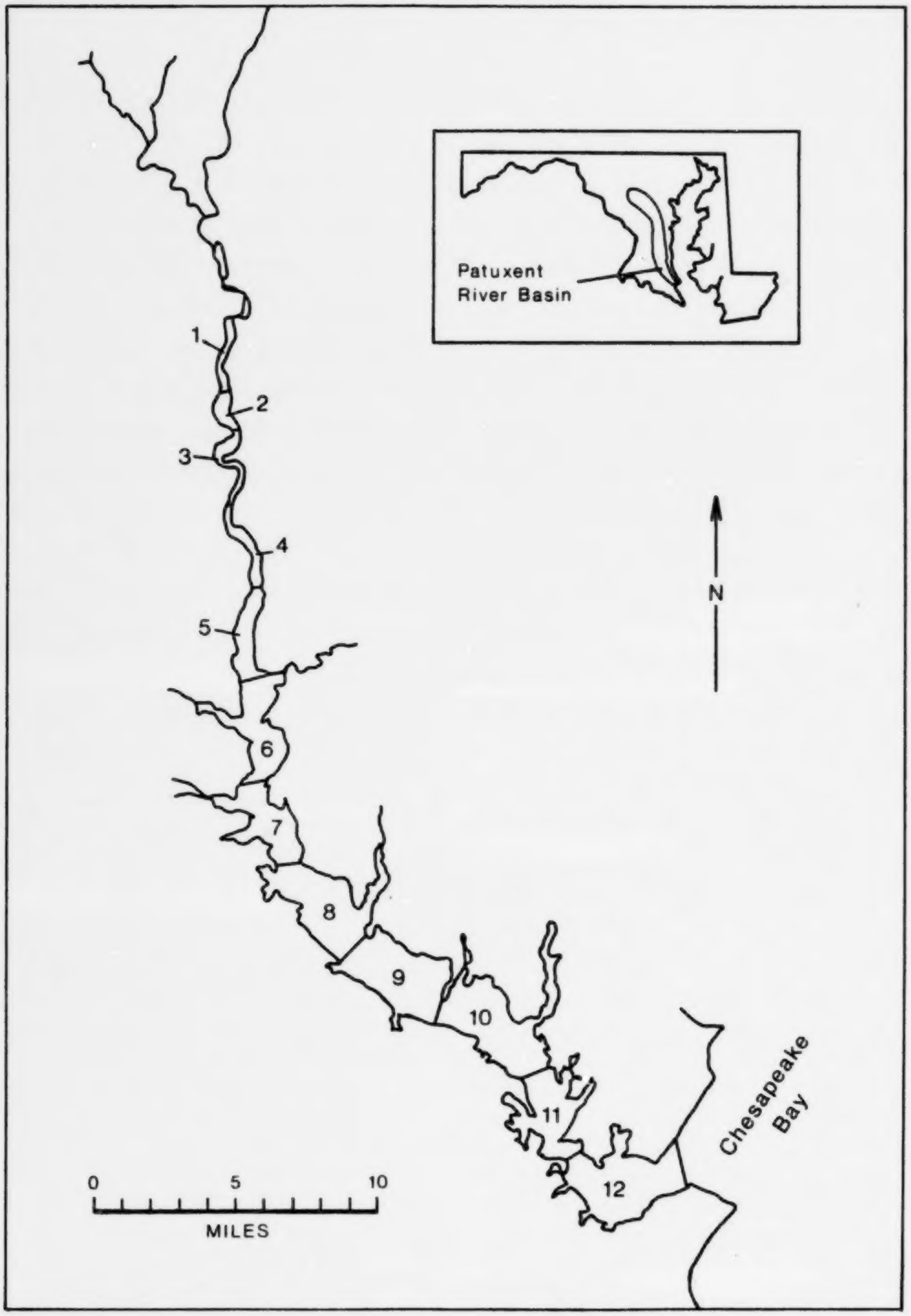


FIGURE VI-26 PATUXENT ESTUARY MODEL SEGMENTATION

conservative pollutant input at the head of the estuary.

The pollutant distribution was predicted by solving on a computer the 12-segment, 2-layer system (24 simultaneous equations). The salinity distribution shown in Table VI-18 was used as input data. As a point of interest, the same network was solved using the model WASP (courtesy of Robert Ambrose, ERL, U.S. Environmental Protection Agency, Athens, Georgia), which is a dynamic two-dimensional estuary model. Instead of using salinity directly, WASP predicts the salinity distribution based on dispersive and advective exchange rates. The salinity distribution predicted by WASP is the same as shown in Table VI-18, which was used as input to Pritchard's Model. After running WASP to steady-state conditions, the pollutant distribution throughout the estuary was virtually the same as predicted by Pritchard's Model.

The pollutant distribution in the Patuxant estuary will be solved in detail using 4 segments instead of 12. The resulting system of 8 simultaneous equations can be solved on a variety of hand-held calculations. The tabulations below show salinities at each segment boundary, and the horizontal flow rates in the upper and lower layers.

Boundary n-1,n	$(S_u)_{n-1,n}$ mg/l-Cl	$(S_l)_{n-1,n}$ mg/l-Cl	$(Q_u)_{n-1,n}$ m^3/sec	$(Q_l)_{n,n-1}$ m^3/sec
0, 1	0.0	0.0	3.3*	0.0
1, 2	4960.	5080.	116.7	113.4
2, 3	9420.	9640.	139.5	136.2
3, 4	11445.	11860.	94.3	91.0
4, 5	13500.	13500.	156.8	153.5

*This is the specified river inflow rate, R.

The flow rates were calculated from Equations VI-48 and VI-49, while the salinities were found directly from Table VI-18.

The salinities within each layer, the salinity and flow rate between the interface of each layer, and the exchange coefficients are tabulated below.

Segment n	$(S_u)_n$ mg/l-Cl	$(S_v)_n$ mg/l-Cl	$(S_l)_n$ mg/l-Cl	$(Q_v)_n$ m^3/sec	E_n m^3/sec
1	1830	1890	1940	113.	3260.
2	8040	8130	8220	23.	3140.
3	10790	10930	11070	-45.	930
4	12100	12380	12650	63.	280.

The flow rates were found from Equation VI-50, and the exchange coefficients from Equation VI-51.

Substituting these data into the pollutant mass balance expressions (Equations VI-54 through VI-59), the following system of equations result:

$$\begin{bmatrix} -6528. & 6638. & -117. & 0. & 0. & 0. & 0. & 0. \\ 6411. & -6525. & 0.0 & 113. & 0. & 0. & 0. & 0. \\ 117. & 0.0 & -6275. & 6297. & -139. & 0. & 0. & 0. \\ 0. & -113. & 6252. & -6275. & 0.0 & 136 & 0. & 0. \\ 0. & 0. & 139. & 0.0 & -1856. & 1811. & -94. & 0. \\ 0. & 0. & 0. & -136. & 1901 & -1856. & 0.0 & 91. \\ 0. & 0. & 0. & 0. & 94. & 0.0 & -561 & 624. \\ 0. & 0. & 0. & 0. & 0. & -91. & 499. & -561 \end{bmatrix} \left\{ \begin{bmatrix} (C_u)_1 \\ (C_l)_1 \\ (C_u)_2 \\ (C_l)_2 \\ (C_u)_3 \\ (C_l)_3 \\ (C_u)_4 \\ (C_l)_4 \end{bmatrix} \right\} = \left\{ \begin{bmatrix} -1.32 \\ 0. \\ 0. \\ 0. \\ 0. \\ 0. \\ 0. \\ 0. \end{bmatrix} \right\}$$

The value -1.32 in the first row of the right-hand side column vector is twice the loading of pollutant which comes into the upper layer of the first segment, as required in Equation VI-56. The units are in gm/sec to be compatible with the units of the remaining terms in the equations:

$$\dot{M} = 125 \text{ lbs/day} = 0.66 \text{ gm/sec}$$

so $$2\dot{M} = 250 \text{ lbs/day} = 1.32 \text{ gm/sec}$$

The pollutant distribution which results from solving the eight linear equations is:

$(C_u)_1 = (0.17)$
$(C_l)_1 = (0.17)$
$(C_u)_2 = (0.08)$
$(C_l)_2 = (0.08)$
$(C_u)_3 = (0.04)$
$(C_l)_3 = (0.04)$
$(C_u)_4 = (0.02)$
$(C_l)_4 = (0.01)$

These values are nearly the same as found when 12 segments were used, which indicates 4 segments are sufficient to accurately predict pollutant distribution for this problem.

END OF EXAMPLE VI-10

6.5 POLLUTANT DISTRIBUTION FOLLOWING DISCHARGE FROM A MARINE OUTFALL

6.5.1 Introduction

Numerous coastal states have enacted water quality standards which limit the maximum allowable concentration of pollutants, particularly metals and organic toxicants, which can be discharged into estuarine and coastal waters. The standards normally permit that an exempt area, called a mixing zone, be defined around the outfall where water quality standards are not applicable. For example, the Water Quality Control Plan for Ocean Waters of California (State Water Resources Control Board, 1978) sets forth the following statement directed at toxic substance limitations:

> "Effluent limitations shall be imposed in a manner prescribed by the State Board such that the concentrations set forth . . . as water quality objectives, shall not be exceeded in the receiving water upon

the completion of initial dilution."

The mixing zone, or zone of initial dilution (ZID), is non-rigorously defined as the volume of water where the wastewater and ambient saline water mix during the first few minutes following discharge, when the plume still has momentum and buoyancy. As the wastewater is discharged, it normally begins to rise because of its buoyancy and momentum, as illustrated in Figure VI-27.

If the ambient water column is stratified and the water depth is great enough, the rising plume will not reach the surface of the water, but rather will stop at the level where the densities of the plume and receiving water become equal. This level is called the plume's trapping level. (See Figure VI-27.) Due to residual momentum, the plume might continue to rise beyond the trapping level, but will tend to fall back after the momentum is completely dissipated. Once the plume stops rising, the waste field begins to drift away from the ZID with the ambient currents. At this time, initial dilution is considered complete. Section 6.5.2, which follows, shows how initial dilution is calculated, and then Sections 6.5.3 and 6.5.4 illustrate how pollutant concentrations at the completion of initial dilution can be predicted. Sections 6.5.5 and 6.5.6 explain methods of predicting pollutant and dissolved oxygen concentrations, respectively, as the waste field migrates away from the ZID.

The methods presented in section 6.5.2 through 6.5.6 are applicable to stratified or non-stratified estuaries, embayments, and coastal waters. The methods assume that reentrainment of previously discharged effluent back into the ZID is negligible. Reentrainment can occur if the wastewater is discharged into a confined area where free circulation is impaired or because of tidal reversals in narrow estuaries.

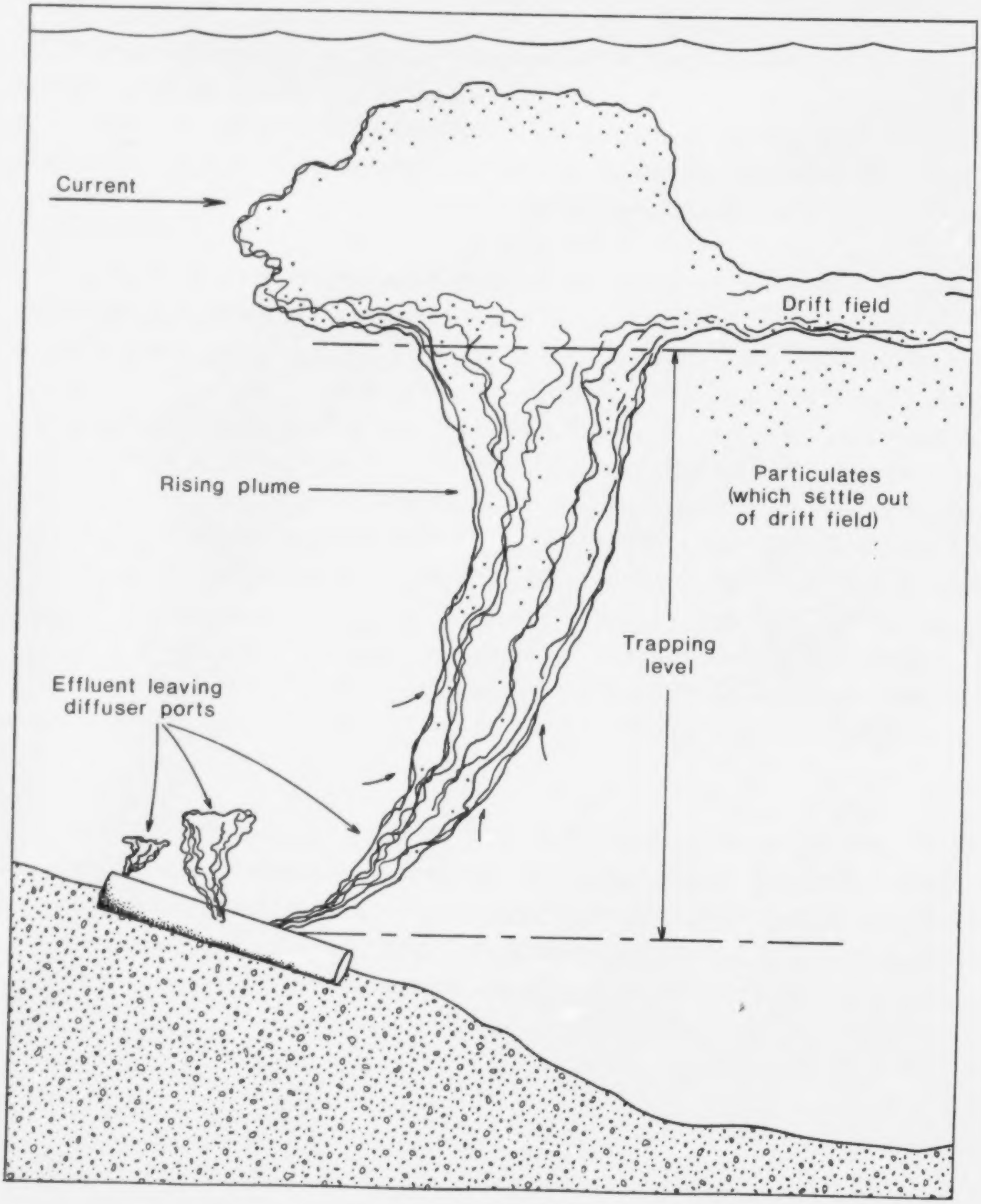

Current
Drift field
Rising plume
Particulates (which settle out of drift field)
Trapping level
Effluent leaving diffuser ports

FIGURE VI-27 WASTE FIELD GENERATED BY MARINE OUTFALL

6.5.2 Prediction of Initial Dilution

6.5.2.1 General

Discharge to bodies of water through submerged diffusers is a common waste water management technique. A diffuser is typically a pipe with discharge ports spaced at regular intervals. Such discharges are often buoyant with high exit velocity relative to the ambient velocity. The resulting waste streams act as plumes or buoyant jets. The velocity shear between ambient and plume fluids results in the incorporation of ambient fluid into the plume, a process called entrainment. Initial dilution results from the entrainment of ambient fluid into the plume as the plume rises to its trapping level.

The magnitude of initial dilution depends on a number of factors including, but not limited to, the depth of water, ambient density stratification, discharge rate, buoyancy, port spacing (i.e. plume merging), and current velocity. These factors may be referred to collectively as the diffuser flow configuration or simply the flow configuration. Depending on the flow configuration, the initial dilution may be less than 10 or greater than 500. As attaining water quality criteria may often require relatively high initial dilution, the need to be able to estimate initial dilution for various flow configurations becomes apparent.

Other than actually sampling the water after a facility is in operation, there are various ways to estimate pollutant concentrations achieved in the vicinity of a particular diffuser. A scale model faithful to all similarity criteria could yield the necessary dilution information. Dimensional analysis and empirical formulae may also be very useful. Alternatively, a numerical model based on the laws of physics may be developed. This method is chosen to provide initial dilution estimates here because it is more cost-effective than field sampling and more accurate than a scale model.

Any numerical model used to provide dilution estimates should faithfully replicate the relevant plume relationships and should be verified for accuracy. The plume model MERGE (Frick, 1981c) accounts for the effects of current ambient density stratification and port spacing on plume behavior. In addition, it has been extensively verified (Frick, 1981a, 1981b; Tesche *et al.*, 1980;

Policastro et al., 1980; Carhart et al., 1981).

There are several ways of presenting the initial dilution estimates. MERGE may be run for specific cases or run for many cases spanning a range of conditions and presented in nomogram or tabular form. The latter method is the most compact. The resulting initial dilution tables display values of dilution achieved at the indicated depths and densimetric Froude numbers. One hundred tables are presented in Appendix G for various combinations of port spacing, density stratification, and effluent-to-current velocity ratio.

Before describing the tables in more detail and discussing examples, it may be helpful for some users to read the following, occasionally technical, discussions of the plume model MERGE (Section 6.5.2.2) and of basic principles of similarity (Section 6.5.2.3). Others may want to advance directly to Section 6.5.2.4 describing table usage.

6.5.2.2 The Plume Model MERGE

MERGE is the latest in a series of models whose development began in 1973. Various stages of model development have been recorded (Winiarski and Frick, 1976 and 1978; Frick, 1981c). In the realm of plume modeling, MERGE belongs to the Lagrangian minority since more models are Eulerian. The model can be demonstrated to be basically equivalent to its Eulerian counterparts (Frick and Winiarski, 1975; Frick, 1981c). Time is the independent variable which is incremented in every program iteration based on the rate of entrainment.

To simplify the problem, many assumptions and approximations are made in plume modeling. In MERGE, steady-state is assumed and the plume is assumed to have a round cross section everywhere.

The MERGE user may input arbitrary current and ambient density profiles. The model includes a compressible equation of continuity so that the predictions are also valid for highly buoyant plumes. It accounts for merging of adjacent plumes but only when the ambient current dilution is normal to the diffuser pipe. In many cases, this is not a significant restriction as many diffusers are oriented to be normal to the prevailing current direction.

The model contains an option for using either constant or variable coefficients of bulk expansion in the equation of state. The water densities in Table VI-19 are generated using the model's density subroutine based on actual temperatures and salinities (i.e. effectively using variable coefficients). If temperature and salinity data are unavailable then the model can be run based on density data alone. The latter method is satisfactory for relatively high temperatures and salinities because the equation of state is relatively linear with these variables in that range. However, for low densities and temperatures gross inaccuracies may result. Unfortunately, the initial dilution tables are based on the latter method. A more accurate representation would greatly increase the number of tables necessary to cover all the cases. Users with applications involving cold, low salinity water are urged to run the more accurate form of the model.

The success of MERGE in predicting plume behavior is primarily attributable to two unique model features. The first of these relates to the expression of forced entrainment. Entrainment may be attributed to the velocity shear present even in the absence of currents, i.e. aspiration, and to current-induced entrainment, sometimes called forced entrainment.

The forced entrainment algorithm in MERGE is based on the assumption that all fluid flowing through the upstream projected area of the plume is entrained. This hypothesis is based on well-established principles and observations (Rawn _et al._, 1960; Jirka and Harlman 1973). Paradoxically, the hypothesis has never been implemented in numerical models before. The projected area normally contains linear and quadratic terms in plume diameter, whereas in conventional modeling, forced entrainment is generally expressed as a linear function of diameter. It is necessary to include additional sources of entrainment to make up the difference when so expressed.

The second feature is the use of a constant aspiration coefficient. This coefficient is often considered to be variable (e.g. Fan, 1967). The need for a variable coefficient is attributable to the fact that many models predict centerline plume values. For plumes discharged vertically upward into density stratified ambient water, such models are expected to predict the maximum penetration of the plume. To achieve agreement requires a relatively small aspiration coefficient. However, when the same models are used to predict the

Table VI-19a

WATER DENSITIES (EXPRESSED AS SIGMA-T)* CALCULATED USING THE DENSITY SUBROUTINE FOUND IN MERGE

TEMPERATURE(°C)

SALINITY (‰)	0		2		4		5		8		10		12		14
0	-0.093	-0.034	.007	.031	.039	.030	.006	-0.032	-0.086	-0.154	-0.235	-0.330	-0.438	-0.558	-0.691
	.721	.776	.814	.835	.839	.827	.800	.758	.702	.632	.548	.450	.340	.217	.082
	1.535	1.586	1.620	1.637	1.638	1.623	1.593	1.548	1.489	1.416	1.329	1.230	1.117	.992	.854
	2.348	2.395	2.425	2.439	2.437	2.419	2.385	2.338	2.276	2.200	2.111	2.008	1.893	1.766	1.626
	3.159	3.203	3.230	3.240	3.234	3.213	3.177	3.126	3.061	2.983	2.891	2.786	2.669	2.539	2.397
5	3.970	4.010	4.033	4.040	4.031	4.007	3.968	3.914	3.847	3.765	3.671	3.564	3.444	3.312	3.168
	4.781	4.817	4.836	4.840	4.828	4.800	4.758	4.701	4.631	4.547	4.450	4.341	4.218	4.084	3.938
	5.590	5.623	5.639	5.639	5.623	5.593	5.548	5.488	5.415	5.329	5.229	5.117	4.992	4.856	4.708
	6.399	6.428	6.441	6.437	6.418	6.385	6.337	6.274	6.199	6.109	6.007	5.893	5.766	5.627	5.477
	7.207	7.233	7.242	7.235	7.213	7.176	7.125	7.060	6.982	6.890	6.785	6.668	6.539	6.398	6.245
10	8.015	8.037	8.042	8.032	8.007	7.967	7.913	7.845	7.764	7.670	7.563	7.443	7.312	7.168	7.014
	8.822	8.840	8.842	8.829	8.801	8.758	8.701	8.630	8.546	8.449	8.340	8.218	8.084	7.939	7.782
	9.628	9.643	9.642	9.625	9.594	9.548	9.488	9.415	9.328	9.228	9.116	8.992	8.856	8.708	8.549
	10.434	10.446	10.441	10.421	10.387	10.338	10.275	10.199	10.109	10.007	9.893	9.766	9.628	9.478	9.317
	11.240	11.248	11.240	11.217	11.179	11.127	11.062	10.983	10.890	10.786	10.669	10.540	10.399	10.247	10.084
15	12.045	12.049	12.038	12.012	11.971	11.916	11.848	11.766	11.671	11.564	11.445	11.313	11.170	11.016	10.851
	12.850	12.851	12.836	12.807	12.763	12.705	12.634	12.549	12.452	12.342	12.220	12.087	11.941	11.785	11.618
	13.654	13.652	13.634	13.602	13.555	13.494	13.420	13.332	13.232	13.120	12.996	12.860	12.712	12.554	12.384
	14.459	14.453	14.432	14.396	14.346	14.282	14.205	14.115	14.013	13.898	13.771	13.633	13.483	13.322	13.151
	15.263	15.254	15.229	15.190	15.137	15.071	14.991	14.898	14.793	14.676	14.547	14.406	14.254	14.091	13.917
20	16.067	16.054	16.027	15.985	15.929	15.859	15.777	15.681	15.573	15.453	15.322	15.179	15.025	14.860	14.684
	16.870	16.855	16.824	16.779	16.720	16.647	16.562	16.464	16.354	16.231	16.097	15.952	15.796	15.628	15.451
	17.674	17.655	17.621	17.573	17.511	17.436	17.347	17.247	17.134	17.009	16.873	16.725	16.566	16.397	16.217
	18.478	18.455	18.418	18.367	18.302	18.224	18.133	18.030	17.914	17.787	17.648	17.498	17.337	17.166	16.984
	19.281	19.255	19.215	19.161	19.093	19.012	18.919	18.813	18.694	18.565	18.424	18.271	18.108	17.935	17.751
25	20.085	20.056	20.012	19.955	19.884	19.801	19.704	19.596	19.475	19.343	19.199	19.045	18.880	18.704	18.518
	20.888	20.856	20.810	20.749	20.676	20.589	20.490	20.379	20.256	20.121	19.975	19.819	19.651	19.473	19.285
	21.692	21.657	21.607	21.544	21.467	21.378	21.276	21.162	21.037	20.900	20.751	20.592	20.423	20.243	20.053
	22.496	22.457	22.405	22.338	22.259	22.167	22.063	21.946	21.818	21.678	21.528	21.367	21.195	21.013	20.821
	23.300	23.258	23.202	23.133	23.051	22.956	22.849	22.730	22.599	22.458	22.305	22.141	21.967	21.783	21.589
30	24.104	24.059	24.001	23.929	23.843	23.746	23.636	23.514	23.381	23.237	23.082	22.916	22.740	22.554	22.358
	24.908	24.861	24.799	24.724	24.636	24.536	24.423	24.299	24.164	24.017	23.859	23.691	23.513	23.325	23.127
	25.713	25.662	25.598	25.520	25.429	25.326	25.211	25.084	24.946	24.797	24.637	24.467	24.287	24.097	23.897
	26.518	26.464	26.397	26.316	26.223	26.117	25.999	25.870	25.729	25.578	25.416	25.243	25.061	24.869	24.667
	27.324	27.267	27.196	27.113	27.016	26.908	26.788	26.656	26.513	26.359	26.195	26.020	25.836	25.641	25.437
35	28.130	28.070	27.996	27.910	27.811	27.700	27.577	27.442	27.297	27.141	26.974	26.798	26.611	26.414	26.208
	28.936	28.873	28.797	28.708	28.606	28.492	28.366	28.230	28.082	27.923	27.754	27.575	27.387	27.188	26.980
	29.743	29.677	29.598	29.506	29.401	29.285	29.157	29.017	28.867	2*.706	28.535	28.354	28.163	27.963	27.753
	30.550	30.482	30.399	30.305	30.197	30.078	29.948	29.806	29.653	29.490	29.317	29.133	28.940	28.738	28.526
	31.358	31.287	31.202	31.104	30.994	30.872	30.739	30.595	30.440	30.275	30.099	29.913	29.718	29.514	29.300
40	32.167	32.092	32.005	31.904	31.792	31.667	31.532	31.385	31.227	31.060	30.882	30.694	30.497	30.290	30.075

*Sigma-t (σ_t) is defined as: (density-1) x 10^3. For example, for seawater with a density of 1.02500 g/cm^3, σ_t = 25.

Table VI-19b

WATER DENSITIES (EXPRESSED AS SIGMA-T)* CALCULATED USING THE DENSITY SUBROUTINE FOUND IN MERGE

TEMPERATURE (°C)

SALINITY (‰)		16		18		20		22		24		26		28	
0	-0.836	-0.993	-1.161	-1.341	-1.532	-1.733	-1.945	-2.167	-2.399	-2.641	-2.893	-3.154	-3.425	-3.704	-3.993
	-0.065	-0.224	-0.394	-0.576	-0.763	-0.971	-1.185	-1.409	-1.642	-1.886	-2.139	-2.402	-2.674	-2.956	-3.246
	.705	.544	.372	.189	-0.006	-0.211	-0.426	-0.651	-0.887	-1.132	-1.387	-1.651	-1.925	-2.208	-2.499
	1.475	1.312	1.138	.952	.756	.550	.333	.106	-0.131	-0.378	-0.635	-0.901	-1.176	-1.460	-1.753
	2.244	2.079	1.903	1.716	1.518	1.309	1.091	.862	.623	.375	.117	-0.150	-0.427	-0.713	-1.007
5	3.012	2.845	2.667	2.478	2.279	2.069	1.848	1.619	1.377	1.127	.868	.599	.321	.034	-0.262
	3.780	3.611	3.431	3.240	3.039	2.827	2.605	2.373	2.131	1.880	1.619	1.348	1.069	.780	.483
	4.548	4.377	4.195	4.002	3.799	3.585	3.362	3.128	2.884	2.631	2.369	2.097	1.816	1.526	1.228
	5.315	5.142	4.958	4.763	4.558	4.343	4.118	3.882	3.637	3.383	3.119	2.846	2.563	2.272	1.972
	6.082	5.907	5.721	5.524	5.317	5.100	4.873	4.636	4.390	4.134	3.868	3.594	3.310	3.017	2.716
10	6.848	6.671	6.483	6.285	6.076	5.857	5.629	5.390	5.142	4.885	4.618	4.342	4.057	3.763	3.460
	7.614	7.435	7.245	7.045	6.835	6.614	6.384	6.144	5.894	5.635	5.367	5.089	4.803	4.507	4.203
	8.379	8.198	8.007	7.805	7.593	7.371	7.139	6.897	6.646	6.385	6.116	5.837	5.549	5.252	4.947
	9.145	8.962	8.768	8.565	8.351	8.127	7.893	7.650	7.397	7.135	6.864	6.584	6.295	5.997	5.690
	9.910	9.725	9.530	9.324	9.108	8.883	8.648	8.403	8.149	7.885	7.613	7.331	7.041	6.741	6.433
15	10.675	10.488	10.291	10.093	9.866	9.639	9.402	9.156	8.900	8.635	8.361	8.078	7.786	7.486	7.176
	11.439	11.251	11.052	10.843	10.623	10.395	10.156	9.908	9.651	9.385	9.109	8.825	8.532	8.230	7.920
	12.204	12.013	11.813	11.602	11.381	11.150	10.910	10.661	10.402	10.134	9.859	9.572	9.278	8.975	8.663
	12.969	12.776	12.573	12.361	12.138	11.906	11.664	11.413	11.153	10.884	10.606	10.319	10.023	9.719	9.406
	13.733	13.539	13.334	13.120	12.895	12.662	12.419	12.166	11.904	11.634	11.354	11.066	10.769	10.464	10.149
20	14.498	14.301	14.095	13.879	13.653	13.417	13.173	12.919	12.656	12.384	12.103	11.813	11.515	11.208	10.893
	15.262	15.064	14.856	14.638	14.410	14.173	13.927	13.671	13.407	13.134	12.851	12.560	12.261	11.953	11.637
	16.027	15.827	15.617	15.397	15.168	14.929	14.681	14.424	14.158	13.884	13.600	13.308	13.007	12.698	12.381
	16.792	16.590	16.378	16.156	15.925	15.685	15.436	15.177	14.910	14.634	14.349	14.056	13.754	13.443	13.125
	17.557	17.353	17.139	16.916	16.683	16.441	16.190	15.931	15.662	15.384	15.098	14.803	14.500	14.189	13.869
25	18.322	18.116	17.901	17.676	17.441	17.198	16.945	16.684	16.414	16.135	15.848	15.552	15.247	14.935	14.614
	19.087	18.880	18.662	18.436	18.200	17.955	17.701	17.438	17.166	16.886	16.597	16.300	15.995	15.681	15.359
	19.853	19.643	19.424	19.196	18.958	18.712	18.456	18.192	17.919	17.637	17.347	17.049	16.742	16.428	16.105
	20.619	20.408	20.187	19.957	19.717	19.469	19.212	18.946	18.672	18.389	18.098	17.798	17.490	17.175	16.851
	21.385	21.172	20.949	20.718	20.477	20.227	19.968	19.701	19.425	19.141	18.849	18.548	18.239	17.922	17.597
30	22.152	21.937	21.713	21.479	21.236	20.985	20.725	20.456	20.179	19.894	19.600	19.298	18.988	18.670	18.344
	22.919	22.702	22.476	22.241	21.997	21.744	21.482	21.212	20.934	20.647	20.352	20.049	19.738	19.419	19.091
	23.687	23.468	23.240	23.003	22.757	22.503	22.240	21.968	21.689	21.401	21.104	20.800	20.488	20.168	19.840
	24.455	24.235	24.005	23.766	23.519	23.263	22.998	22.725	22.444	22.155	21.857	21.552	21.239	20.917	20.588
	25.224	25.001	24.770	24.530	24.281	24.023	23.757	23.483	23.200	22.910	22.611	22.304	21.990	21.668	21.338
35	25.993	25.769	25.536	25.294	25.043	24.784	24.516	24.241	23.957	23.665	23.365	23.058	22.742	22.419	22.088
	26.763	26.537	26.302	26.058	25.806	25.545	25.277	24.999	24.714	24.421	24.120	23.811	23.495	23.171	22.839
	27.534	27.306	27.069	26.824	26.570	26.308	26.037	25.759	25.472	25.178	24.876	24.566	24.248	23.923	23.590
	28.305	28.075	27.837	27.590	27.334	27.071	26.799	26.519	26.231	25.936	25.632	25.321	25.003	24.677	24.343
	29.077	28.846	28.605	28.357	28.100	27.834	27.561	27.280	26.991	26.694	26.390	26.078	25.758	25.431	25.096
40	29.850	29.617	29.375	29.124	28.866	28.599	28.324	28.042	27.751	27.453	27.148	26.835	26.514	26.186	25.851

*Sigma-t (σ_t) is defined as: (density-1) x 10^3. For example, for seawater with a density of 1.02500 g/cm^3, $\sigma_t = 25$.

Table VI-19c

WATER DENSITIES (EXPRESSED AS SIGMA-T)* CALCULATED USING THE DENSITY SUBROUTINE FOUND IN MERGE

TEMPERATURE (°C)

SALINITY (‰)	30		32		34		36		38		40		42		44
0	-4.291	-4.597	-4.912	-5.235	-5.567	-5.906	-6.254	-6.610	-6.973	-7.345	-7.723	-8.110	-8.533	-8.904	-9.313
	-3.545	-3.853	-4.169	-4.494	-4.827	-5.168	-5.518	-5.875	-6.240	-6.613	-6.993	-7.381	-7.777	-8.180	-8.590
	-2.800	-3.109	-3.427	-3.753	-4.088	-4.430	-4.781	-5.140	-5.507	-5.881	-6.263	-6.653	-7.050	-7.455	-7.867
	-2.055	-2.366	-2.685	-3.013	-3.349	-3.693	-4.045	-4.405	-4.774	-5.150	-5.534	-5.925	-6.324	-6.730	-7.144
	-1.311	-1.623	-1.943	-2.273	-2.610	-2.956	-3.309	-3.671	-4.041	-4.418	-4.804	-5.197	-5.597	-6.006	-6.421
5	-0.567	-0.890	-1.202	-1.533	-1.872	-2.219	-2.574	-2.937	-3.308	-3.687	-4.074	-4.469	-4.871	-5.281	-5.698
	.177	-0.138	-0.461	-0.793	-1.134	-1.482	-1.839	-2.203	-2.576	-2.956	-3.345	-3.741	-4.145	-4.556	-4.975
	.920	.604	.279	-0.054	-0.396	-0.745	-1.103	-1.469	-1.843	-2.225	-2.615	-3.013	-3.418	-3.831	-4.252
	1.663	1.345	1.019	.685	.342	-0.009	-0.368	-0.736	-1.111	-1.494	-1.886	-2.285	-2.691	-3.106	-3.528
	2.406	2.087	1.759	1.424	1.079	.727	.367	-0.002	-0.379	-0.763	-1.156	-1.556	-1.965	-2.380	-2.804
10	3.148	2.828	2.499	2.162	1.817	1.463	1.101	.731	.354	-0.032	-0.426	-0.828	-1.238	-1.655	-2.080
	3.890	3.569	3.239	2.901	2.554	2.199	1.836	1.465	1.086	.699	.304	-0.099	-0.510	-0.929	-1.355
	4.633	4.310	3.979	3.639	3.291	2.935	2.571	2.199	1.818	1.430	1.034	.629	.217	-0.203	-0.630
	5.375	5.051	4.718	4.378	4.029	3.671	3.306	2.932	2.551	2.161	1.764	1.358	.945	.524	.095
	6.117	5.792	5.458	5.116	4.766	4.408	4.041	3.666	3.284	2.893	2.494	2.088	1.673	1.251	.820
15	6.859	6.532	6.198	5.855	5.503	5.144	4.776	4.400	4.016	3.625	3.225	2.817	2.401	1.978	1.547
	7.601	7.273	6.937	6.593	6.241	5.880	5.511	5.134	4.750	4.357	3.956	3.547	3.130	2.706	2.273
	8.343	8.014	7.677	7.332	6.978	6.617	6.247	5.869	5.483	5.089	4.687	4.277	3.860	3.434	3.001
	9.085	8.755	8.417	8.070	7.716	7.353	6.982	6.604	6.217	5.822	5.419	5.008	4.589	4.163	3.728
	9.827	9.496	9.157	8.809	8.454	8.090	7.718	7.338	6.951	6.555	6.151	5.739	5.320	4.892	4.457
20	10.569	10.237	9.897	9.549	9.192	8.827	8.455	8.074	7.685	7.288	6.884	6.471	6.050	5.622	5.186
	11.312	10.979	10.638	10.288	9.931	9.565	9.191	8.809	8.420	8.022	7.617	7.203	6.782	6.353	5.915
	12.055	11.721	11.378	11.028	10.669	10.303	9.928	9.546	9.155	8.757	8.350	7.936	7.514	7.084	6.646
	12.798	12.463	12.119	11.768	11.408	11.041	10.666	10.282	9.891	9.491	9.084	8.669	8.246	7.816	7.377
	13.541	13.205	12.861	12.508	12.148	11.780	11.403	11.015	10.627	10.227	9.819	9.403	8.980	8.548	8.109
25	14.285	13.948	13.602	13.249	12.888	12.519	12.142	11.757	11.364	10.963	10.554	10.138	9.714	9.282	8.842
	15.029	14.691	14.345	13.990	13.628	13.258	12.881	12.495	12.101	11.700	11.291	10.874	10.449	10.016	9.576
	15.773	15.434	15.087	14.732	14.369	13.999	13.620	13.233	12.839	12.437	12.027	11.610	11.184	10.751	10.310
	16.518	16.178	15.830	15.475	15.111	14.739	14.360	13.973	13.578	13.175	12.765	12.347	11.921	11.487	11.046
	17.264	16.923	16.574	16.217	15.853	15.481	15.101	14.713	14.317	13.914	13.503	13.084	12.658	12.224	11.782
30	18.010	17.668	17.318	16.961	16.596	16.223	15.842	15.454	15.057	14.654	14.242	13.823	13.396	12.962	12.520
	18.757	18.414	18.063	17.705	17.339	16.965	16.584	16.195	15.798	15.394	14.982	14.563	14.136	13.701	13.258
	19.504	19.160	18.809	18.450	18.083	17.709	17.327	16.937	16.540	16.135	15.723	15.303	14.876	14.441	13.998
	20.252	19.907	19.555	19.195	18.828	18.453	18.070	17.680	17.283	16.878	16.465	16.045	15.617	15.182	14.739
	21.000	20.655	20.302	19.941	19.573	19.198	18.815	18.424	18.026	17.621	17.208	16.787	16.359	15.924	15.481
35	21.749	21.403	21.050	20.688	20.320	19.944	19.560	19.169	18.771	18.365	17.952	17.531	17.103	16.667	16.224
	22.499	22.153	21.798	21.436	21.067	20.690	20.306	19.915	19.516	19.110	18.696	18.276	17.847	17.412	16.969
	23.250	22.903	22.547	22.185	21.815	21.438	21.054	20.662	20.263	19.856	19.442	19.021	18.593	18.157	17.714
	24.002	23.653	23.298	22.935	22.564	22.187	21.802	21.409	21.010	20.603	20.190	19.768	19.340	18.904	18.461
	24.754	24.405	24.049	23.685	23.314	22.936	22.551	22.158	21.759	21.352	20.938	20.517	20.088	19.653	19.210
40	25.508	25.158	24.801	24.437	24.065	23.687	23.301	22.908	22.510	22.101	21.687	21.266	20.838	20.402	19.960

---

[*] Sigma-t (σ_t) is defined as: (density-1) x 10^3. For example, for seawater with a density of 1.02500 g/cm^3, σ_t = 25.

trajectories of horizontally discharged buoyant plumes, a larger coefficient is required. Consequently the aspiration coefficient must be variable.

Although relatively advanced, MERGE does have its limitations. Some of these are a result of the assumptions already discussed. For example, the plumes are assumed to be round, whereas some evidence indicates substantial deviation from this idealization (Abramovich, 1963). Other important limitations are listed below.

1. Diffuser parallel current: The model does not predict plume dilution for cases of current flowing parallel to the diffuser pipe. This is a severe limitation especially in some ocean applications because this case may be expected to result in the lowest initial dilutions.

2. Surface entrainment interference: The model does not properly account for interfacial boundary conditions. Dilutions near the surface or bottom may be overestimated because entrainment will be assumed where water is unavailable for entrainment.

3. Horizontal homogeneity: The model assumes homogeneous horizontal current although bottom topography, internal waves, or other factors may cause considerable spatial flow variations. This is in addition to temporal variations which are excluded by virture of assumed steady-state.

4. Uniform discharge: It is assumed that an infinitely long diffuser exists for which there is no port-to-port variation in effluent characteristics.

6.5.2.3 Similarity

The success of a set of tables in describing an infinite number of possible diffuser, effluent, and ambient flow configurations depends on the principles of similarity. Basically, similarity theory states that model and prototype will display equivalent behavior if a limited number of similarity conditions or parameters are preserved. Equivalent behavior means that relative to appropriate measures the behavior will be equal. For example, if all similarity parameters are preserved, then the height of rise predicted by the model and observed in the prototype will be equal when measured in terms of the initial diameters of the corresponding plumes.

The number of similarity conditions is determined by the difference between the number of independent variables and primary variables involved in the problem (Streeter, 1961). Primary variables must include mass, time, and distance. The present problem involves eleven independent variables implying eight similarity conditions. The independent variables, corresponding symbols, units, similarity parameters, and their names are listed in Table VI-20. As the dilution tables are based on a linear equation of state, the effluent and ambient densities p_e and p_a, respectively, replace four independent variables: the effluent and ambient salinities and temperatures. This effectively reduces the number of similarity conditions by two to six.

It is advantageous to further reduce the number of similarity conditions to minimize the number of tables necessary to represent the flow configuratons of interest. From experimental observations, it is found that plume behavior is basically invariant for large Reynolds numbers reducing the number of similarity conditions to five. Finally, the ratio p_e/p_a and the stratification parameter can be combined in a composite stratification parameter, SP, where,

$$SP = (p_a - p_e)/(d_o dp_a/dz)$$

This is a satisfactory similarity parameter providing that differences in model and prototype densities are not too great. The assumption is valid for discharge of municipal waste water into estuarine or coastal waters.
Figures VI-28 and VI-29 demonstrate the effectiveness of this parameter. The same similarity conditions are shared for both cases. The two figures show rise

Table VI-20

PLUME VARIABLES, UNITS, AND SIMILARITY CONDITIONS

Variable	Symbol	Units	Dimensionless Sim. Parm	Name
Effluent density	p_e	ML^{-3}	none--primary variable	none
Effluent velocity	v	LT^{-1}	none--primary variable	none
Effective diameter	d_o	L	none--primary variable	none
Ambient density	p_a	ML^{-3}	p_e/p_a	density ratio
Reduced gravity	g'	LT^{-2}	$v/\sqrt{g'd_o}$	densimetric Froude number: Fr
Density stratification	dp_a/dz	ML^{-4}	$p_e/(d_o dp_a/dz)$	stratification parm.
Current velocity	u_a	LT^{-1}	u_a/v	current to effluent velocity ratio: k
Kinematic viscosity	ν	L^2T^{-1}	d_o/ν	Reynolds number: Re
Port spacing	S_1	L	S_1/d_o	Port spacing parm.: PS

Notes: 1. $g' = ((p_a - p_e)/p_e)g$ where g is the acceleration of gravity (9.807 $msec^{-2}$).

2. In the present application a composite stratification parameter, SP, is used in lieu of the density ratio and the stratification parameter. $SP = (p_a - p_e)/(d_o dp_a/dz)$.

3. The diameter, d_o is taken to be the vena contracta diameter.

```
CASE NUMBER    1

*****   TEST OF COMPOSITE STRATIFICATION PARAMETER

INPUT DATA PSEUDO-ECHO

       U          V          A          T          S          B        SPC     ALT DEN
    7.0200     0.0000     0.1160     0.0000     0.0000     0.0500   100.0000    0.0000

  NDP ITFR IFRQ  NAA  NAB  NAC IDENSW
    2 1000   25    0    0    0    1

(IF IDENSW=1 THEN DENSITY VERSION USED--USE 2ND SIGMAT COL)

AMBIENT STRATIFICATION (AND CALCULATED SIGMAT)

  DEPTH(M)    TEMP(C) SAL(O/OO)  CUR(M/S)     SIGMAT    SIGMAT(DEN VER)
    0.000      0.000     0.000     0.000     -0.093     0.000
 . 10.000      0.000     0.000     0.000     -0.093    27.000

EFFLUX TO CURRENT RATIO(K) . . .=    99999.0
DENSIMETRIC FROUDE NO. . . . . .=       43.1
VOLUME FLUX(M**3/S). . . . . . .=      0.055
DEPTH AVE STRATIFICATION PARM. .=     3703.7
DEPTH(M) . . . . . . . . . . . .=       10.0
DISCHARGE VELOCITY(M/S). . . . .=       7.02
CURRENT SPEED(M/S) . . . . . . .=      0.000
PORT RADIUS(M) . . . . . . . . .=     0.0500
PORT SPACING(M). . . . . . . . .=     100.00

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                                       MODEL OUTPUT AFTER -J- ITERATIONS (MKS UNITS)

    J  HOR CUR(X)     DEPTH(Z)     DIAMETER      VOL DIL  HOR VEL(U)  VER VEL(V)   TOTAL VEL    DEN DIFF        TIME      CURRENT
    1       0.001       10.000        0.100        1.007       6.972       0.000       6.972      26.913       0.000        0.000
   25       0.040       10.000        0.118        1.184       5.903       0.001       5.903      22.704       0.006        0.000
   50       0.087       10.000        0.140        1.403       4.964       0.003       4.964      19.092       0.015        0.000
   75       0.143       10.000        0.167        1.664       4.174       0.004       4.174      16.054       0.027        0.000
  100       0.210       10.000        0.198        1.973       3.510       0.006       3.510      13.500       0.045        0.000
  125       0.290       10.000        0.235        2.342       2.952       0.008       2.952      11.351       0.070        0.000
  150       0.385        9.999        0.279        2.780       2.482       0.010       2.482       9.545       0.105        0.000
  175       0.497        9.999        0.332        3.301       2.087       0.012       2.087       8.025       0.155        0.000
  200       0.632        9.998        0.395        3.921       1.755       0.015       1.755       6.746       0.226        0.000
  225       0.792        9.996        0.469        4.657       1.476       0.018       1.476       5.668       0.326        0.000
  250       0.982        9.993        0.558        5.534       1.241       0.021       1.241       4.760       0.468        0.000
  275       1.208        9.989        0.663        6.576       1.044       0.026       1.044       3.991       0.668        0.000
  300       1.477        9.981        0.788        7.815       0.878       0.031       0.878       3.336       0.951        0.000
  325       1.797        9.967        0.936        9.289       0.738       0.037       0.739       2.772       1.352        0.000
  350       2.177        9.944        1.113       11.042       0.620       0.043       0.622       2.276       1.917        0.000
  375       2.628        9.907        1.321       13.127       0.522       0.051       0.524       1.822       2.715        0.000
  400       3.162        9.845        1.568       15.606       0.439       0.058       0.443       1.382       3.839        0.000
  425       3.792        9.747        1.859       18.555       0.369       0.065       0.375       0.923       5.416        0.000
  450       4.534        9.601        2.202       22.064       0.310       0.067       0.317       0.417       7.624        0.000

NOMINAL TRAPPING LEVEL REACHED
  469       5.184        9.454        2.508       25.169       0.272       0.062       0.279      -0.001       9.877        0.000
  475       5.408        9.403        2.615       26.238       0.261       0.059       0.268      -0.135      10.720        0.000
  500       6.457        9.196        3.130       31.204       0.219       0.033       0.222      -0.627      15.137        0.000
  519       7.407        9.127        3.592       35.806       0.192      -0.001       0.192      -0.740      19.769        0.000
```

FIGURE VI-28 EXAMPLE OUTPUT OF MERGE - CASE 1

```
CASE NUMBER    2

*****   TEST OF COMPOSITE STRATIFICATION PARAMETER

INPUT DATA PSEUDO-ECHO

       U          V          A          T          R          R        SPC    ALT DEN
   2.3400     0.0000     0.1160     0.0000     0.0000     0.0500   100.0000    0.0000

  NDP ITER IFRQ  NAA  NAB  NAC IDENSW
    2 1000   25    0    0    0    1

(IF IDENSW=1 THEN DENSITY VERSION USED--USE 2ND SIGMAT COL)

AMBIENT STRATIFICATION (AND CALCULATED SIGMAT)

  DEPTH(M)    TEMP(C) SAL(O/OO)  CUR(M/S)     SIGMAT     SIGMAT(DEN VER)
    0.000      0.000     0.000     0.000     -0.093       0.000
   10.000      0.000     0.000     0.000     -0.093       3.000

EFFLUX TO CURRENT RATIO(K) . . .=    99999.0
DENSIMETRIC FROUDE NO. . . . . .=       43.1
VOLUME FLUX(M**3/S). . . . . . .=      0.018
DEPTH AVE STRATIFICATION PARM. .=    33333.3
DEPTH(M) . . . . . . . . . . . .=       10.0
DISCHARGE VELOCITY(M/S). . . . .=       2.34
CURRENT SPEED(M/S) . . . . . . .=      0.000
PORT RADIUS(M) . . . . . . . . .=     0.0500
PORT SPACING(M). . . . . . . . .=     100.00

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                                     MODEL OUTPUT AFTER -J- ITERATIONS (MKS UNITS)

  J  HOR COR(X)     DEPTH(Z)     DIAMETER      VOL DIL  HOR VEL(U)  VER VEL(V)    TOTAL VEL     DEN DIFF         TIME      CURRENT
  1       0.001       10.000        0.100        1.007       2.324       0.000        2.324        2.979        0.001        0.000
 25       0.041       10.000        0.118        1.189       1.968       0.000        1.968        2.573        0.019        0.000
 50       0.089       10.000        0.141        1.413       1.655       0.001        1.655        2.121        0.046        0.000
 75       0.146       10.000        0.167        1.680       1.391       0.001        1.391        1.784        0.084        0.000
100       0.214       10.000        0.199        1.997       1.170       0.002        1.170        1.500        0.138        0.000
125       0.295       10.000        0.237        2.374       0.984       0.003        0.984        1.261        0.214        0.000
150       0.392        9.999        0.282        2.823       0.827       0.003        0.827        1.061        0.322        0.000
175       0.506        9.999        0.335        3.356       0.696       0.004        0.696        0.892        0.474        0.000
200       0.643        9.998        0.398        3.991       0.585       0.005        0.585        0.749        0.689        0.000
225       0.805        9.996        0.473        4.746       0.492       0.006        0.492        0.630        0.994        0.000
250       0.998        9.993        0.563        5.643       0.414       0.007        0.414        0.529        1.425        0.000
275       1.227        9.988        0.669        6.710       0.348       0.009        0.348        0.443        2.034        0.000
300       1.500        9.980        0.796        7.979       0.293       0.011        0.293        0.370        2.895        0.000
325       1.824        9.966        0.946        9.488       0.246       0.013        0.246        0.308        4.112        0.000
350       2.209        9.942        1.124       11.283       0.207       0.015        0.207        0.252        5.830        0.000
375       2.666        9.902        1.336       13.417       0.174       0.017        0.175        0.201        8.254        0.000
400       3.206        9.838        1.585       15.955       0.146       0.020        0.148        0.152       11.666        0.000
425       3.843        9.736        1.879       18.973       0.123       0.022        0.125        0.100       16.450        0.000
450       4.592        9.585        2.225       22.563       0.103       0.023        0.106        0.043       23.140        0.000

NOMINAL TRAPPING LEVEL REACHED
468       5.213        9.143        2.518       25.561       0.091       0.021        0.094       -0.002       29.563        0.000
475       5.476        9.382        2.644       26.832       0.087       0.020        0.089       -0.019       32.525        0.000
500       6.537        9.177        3.167       31.909       0.073       0.010        0.074       -0.073       45.931        0.000
517       7.388        9.117        3.583       35.900       0.065       0.008        0.065       -0.083       58.378        0.000
```

FIGURE VI-29 EXAMPLE OUTPUT OF MERGE - CASE 2

and dilution to be within about a percent of each other even though the stratification and initial buoyancies are much different. With only four similarity conditions to be satisfied, the problem can be represented by considerably fewer model runs than if six similarity conditions were required.

6.5.2.4 Table Usage

To use the dilution tables to estimate dilutions, it is necessary to calculate the appropriate similarity parameters and know the depth of the outfall. Calculation of the four similarity parameters Fr, SP, k, and PS, given in Table VI-20 requires knowledge of all the variables except v. The dilution tables are shown in Appendix G.

The depth used in the dilution tables is expressed in terms of the diameter of the ports; that is, the vena contracta diameter. For bell-mouthed ports, this diameter is approximately equal to the physical diameter of the port. Thus, if the actual depth of water is 10 m and the port diameter is 10 cm, then the depth of water is 100-port diameters.

The dilution tables are numbered from 1 through 100 and are grouped by port spacing as listed below:

Tables	Port Spacing (PS) (Diameters)
1-20	2
21-40	5
41-60	10
61-80	25
81-100	1000 (effluent from each port acts as a single plume)

Each group of 20 is further subdivided by current velocity to effluent velocity ratio (k), i.e.,

Tables	Current Velocity to Effluent Velocity Ratio (k)
1-5	0.1
6-10	0.05
11-15	0.02
16-20	0.00 (no current)

Each subgroup of five tables is comprised of tables of varying composite density stratification (SP):

Tables	Composite Stratification Parameter (SP)
1	200 (high stratification)
2	500
3	2000
4	10000
5	infinity (no stratification)

Finally, each table includes densimetric Froude number, Fr = 1, 3, 10, 30, 100, and 1000 to represent cases ranging from highly buoyant plumes to almost pure jets. The dilutions are tabulated with plume rise. The following examples demonstrate how the tables may be applied.

EXAMPLE VI-11

Calculation of Initial Dilution

Example A. This example demonstrates many of the basic features of the dilution tables and their usage. It also includes a method for estimating the plume diameter indirectly using information derived from the tables. The method is used in cases of unmerged or slightly merged plumes and is necessary to better estimate plume dilution when the plume is shown to interact with the water surface.

Given that waste water is discharged horizontally at a depth of 66 m from a simple pipe opening and that:

u_a = the current velocity = 0.15 m/s

v = the effluent velocity = 1.5 m/s

p_e = the effluent density = 1000 kg/m^3

p_a = the ambient density at discharge depth = 1015 kg/m^3

L = the port spacing = 3.4 m

d_o = the port discharge vena contracta diameter = 1.7 m, and

dp_a/dz = the ambient density stratification = 0.0441 kg/m^4.

The four similarity parameters necessary to use the tables are:

Fr = the densimetric Froude number = 3.0

k = the current to effluent velocity ratio = 0.1

SP = the composite stratification parameter = 200, and

PS = the port spacing parameter = infinity.

The infinite port spacing indicates that the dilutions will be found in the last 20 tables of the dilution tables in Appendix G, i.e. Tables 81-100. These tables are appropriate because merging does not occur with PS = infinite. The current to effluent velocity ratio of 0.1 indicates that the appropriate dilutions are among the first five of these 20 tables. The stratification parameter 200 identifies the first of these five tables as the correct reference location. Finally, the densimetric Froude number of 3.0 isolates the second column as the one containing the information of interest.

The column of dilutions contains a wealth of information about the plume whose overall behavior is described in Figure VI-30. After rising one diameter (1.7 m), the average plume dilution (expressed in terms of volume dilution) is 2.8. In other words, a given amount of plume volume has been diluted with 1.8 times as much ambient fluid. After rising 2 diameters (3.4 m), the average dilution is 3.7, and so on. At 15 diameters rise, the dilution is 21.4. The next entry follows in a line headed by "T", indicating that the initial trapping level has been reached. This means that the plume and ambient densities are equal at this level and momentary equilibrium has been attained. The "trapping" level dilution is 26.2 and the corresponding plume rise, set off in parentheses to the right of the dilution, is 17.0 diameters. The parentheses are a mnemonic for indicating trapping while values set off in square brackets are merging level plume rises.

When a plume intercepts the water surface, it is deprived of some of its entraining surface and consequently the dilution is less than that indicated in the tables. For well-diluted, unmerged or slightly merged plumes, with k not equal to zero, the plume diameter, d, may be estimated:

$$d = d_o \sqrt{D/k} \qquad \text{(VI-61)}$$

In dimensionless units, or diameters:

$$d/d_o = \sqrt{D/k} \qquad \text{(VI-62)}$$

In the present case, the diameter at maximum rise calculated in this way is 25.2 diameters (42.8m). Thus the top of the plume is 34.8 diameters (22.2 + 12.6) above the level of the outfall, i.e. 12.6 diameters above the plume centerline, and 5.2 diameters below the surface. Therefore, surface interaction does not occur.

For the sake of comparison, the plume diameter calculated by the program at maximum rise is 23.5 diameters which compares favorably with the simplified estimate made above.

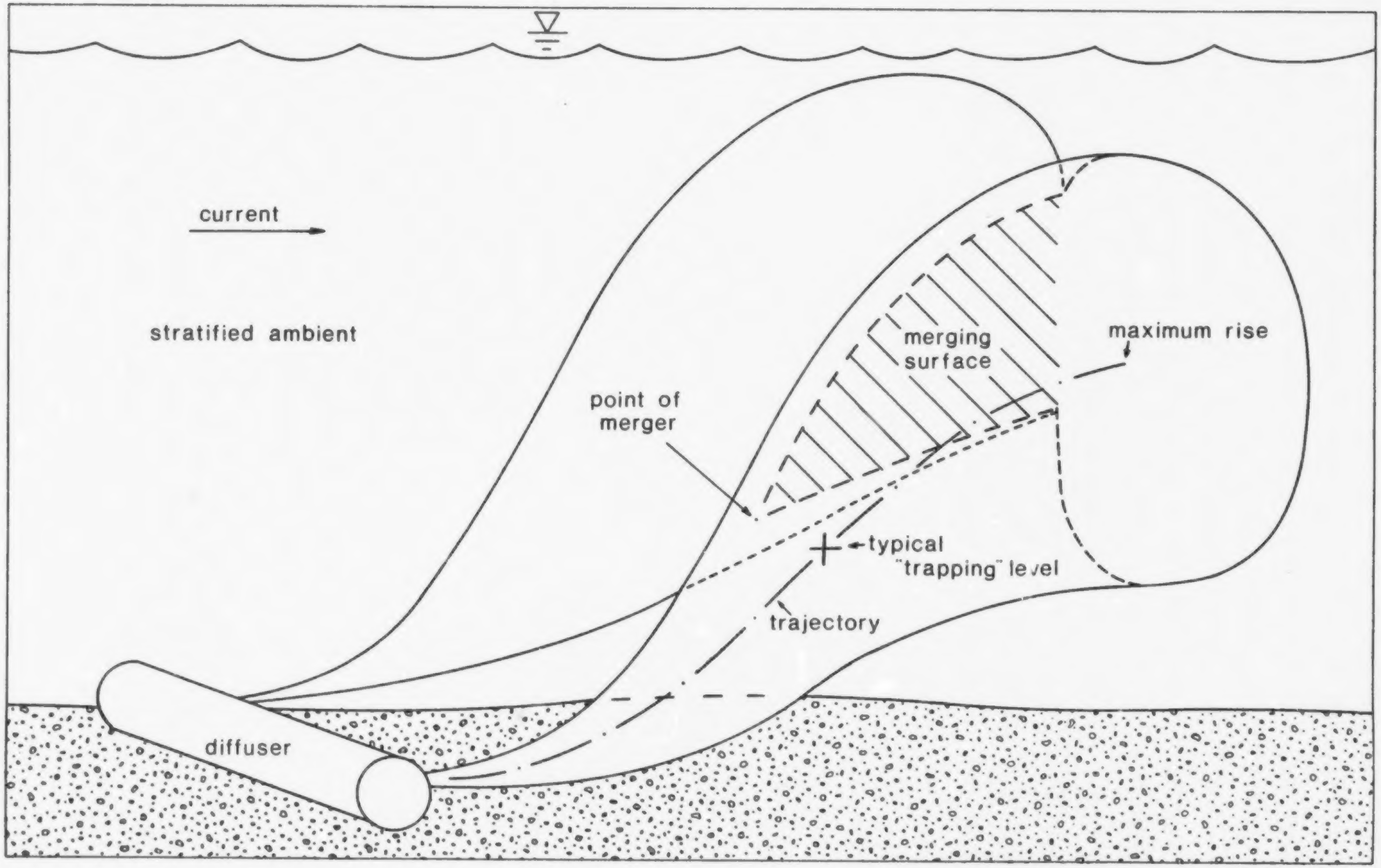


FIGURE VI-30 SCHEMATIC OF PLUME BEHAVIOR PREDICTED BY MERGE IN THE PRESENT USAGE

Example B. Suppose that all the conditions given in Example A apply here except that the depth of water is only 29.7 diameters (50.5 m). Table 81 is again used to provide dilution estimates; however, surface interaction does occur. A conservative estimate of initial dilution is obtained by assuming that entrainment stops as soon as the top boundary of the plume intersects the surface. In reality, some additional ambient water could be expected to enter through the sides of the plume.

When the centerline depth of the plume is 20 diameters, its dilution is 37.3 and its approximate diameter is 19.4 diameters (33 m). Consequently, the top boundary of the plume is 29.7 diameters above the level of the outfall and is equal to the depth of water. Thus the dilution of 37.3 provides a conservative estimate of initial dilution in this case.

Example C. Suppose the following data apply:

$u_a = 0.15$ m/s

$v = 1.5$ m/s

$p_e = 1000$ kg/m

$p_a = 1015$ kg/m

$S_1 = 0.34$ m

$d_o = 0.17$ m, and

$dp_a/dz = 0.0441$ kg/m^4.

Then, Fr = 9.5, k = 0.1, SP = 2000, and PS = 2, and Table 3 in Appendix G is the appropriate source of dilution information. As the Froude number is almost equal to 10, column 3 information can be used without modification although interpolation may be appropriate in some applications. The plumes merge almost immediately at a dilution of 2.1. The initial trapping level is encountered after the plume rises 89.4 diameters (15.2 m). The maximum dilution is 76.2 after rising 125 diameters (21.3).

For closely spaced plumes, the diameter may be estimated from the relationship:

$$d/d_o = (\pi D)\ (4\ k\ PS) \qquad \text{(VI-63)}$$

The maximum diameter estimated in this way is 299 diameters (50.9 m). In contrast, the program gives a value of 268 diameters (45.5 m). No surface intraction occurs in deep water. In very shallow water, a conservative estimate of dilution may be made by dividing the total flow across the length of the diffuser by the flow through the diffuser. It is conservative because no aspiration entrainment is included in the estimate.

Table 3 contains a blank entry in the second column of the 90-diameter rise line. The previous entry in the column indicates trapping. This means that trapping and the 90-diameter rise level occurred in the same iteration. Therefore, the dilution of 41.3 is the appropriate value for this blank.

Example D. The methods given in Examples A and C for estimating the plume diameter are not accurate when intermediate degrees of merging exist. If surface interaction is important, it may be necessary to run the model to obtain accurate plume diameter predictions.

Example E. Sometimes outfalls or diffusers are located in water only a few port diameters deep and, as a result, initial dilutions may be expected to be quite small. However, after the plumes reach the surface, they still have substantial horizontal velocity and continue to entrain ambient water more vigorously than a plume whose trajectory is unhindered by surface constraints. The workbook by Shirazi and Davis (1976) may be consulted to estimate additional dilution.

Example F. Strong stratification inhibits plume rise. As stratification weakens, plume rise and dilution tend to increase. Predicting large dilutions and plume rises can require more program iterations than used to develop the tables in Appendix G. On the other hand, very large dilutions are usually of lesser interest. Consequently, the number of iterations is arbitrarily limited to 1000 and rise to 300 diameters. Table 94 provides examples in which the runs for each densimetric Froude number are limited by the permitted number of iterations. The final dilutions listed are underlined to remind the user that larger dilutions and plume rises occur. When the rise limitation criterion has been reached, a rise of 300 diameters or slightly more will be indicated.

Example G. Many diffusers have horizontally discharging paired ports on each side of the diffuser. In cross current, the resulting plume behavior appears somewhat like that shown in Figure VI-31. The upstream plume is bent over by the counter flowing current and ultimately may be entrained by the downstream plume. The entrainment of pollutant laden fluid will reduce the overall dilution in the merged plumes. Estimates of the magnitude of this effect may be made if it may be assumed that:

1. the interaction occurs
2. there is merging of adjacent plumes to assure cross diffuser merging and not interweaving of plumes
3. the opposite plumes have similar rise and overall entrainment
4. there are no surface constraints, and
5. the actual (not permitted) rise is provided in the tables.

The final dilution of the merged plumes, D_f, is approximately:

$$D_f = (D^2)\ (2D - D_e) \qquad \text{(VI-64)}$$

where D is the dilution at maximum rise of the downstream plume as given in the tables and D_e is the dilution of the downstream plume upon entry into the bottom of the bent over upstream plume (see Figure VI-31). D_e is estimated by finding the distance in diameters, Z_e, between the depth at entry and the port depth. The dilution at this depth is read from the appropriate line in the dilution tables or interpolated. The maximum radius of the plume is added to the depth at which maximum rise occurs. The difference between the port depth and the depth so calculated is Z_e.

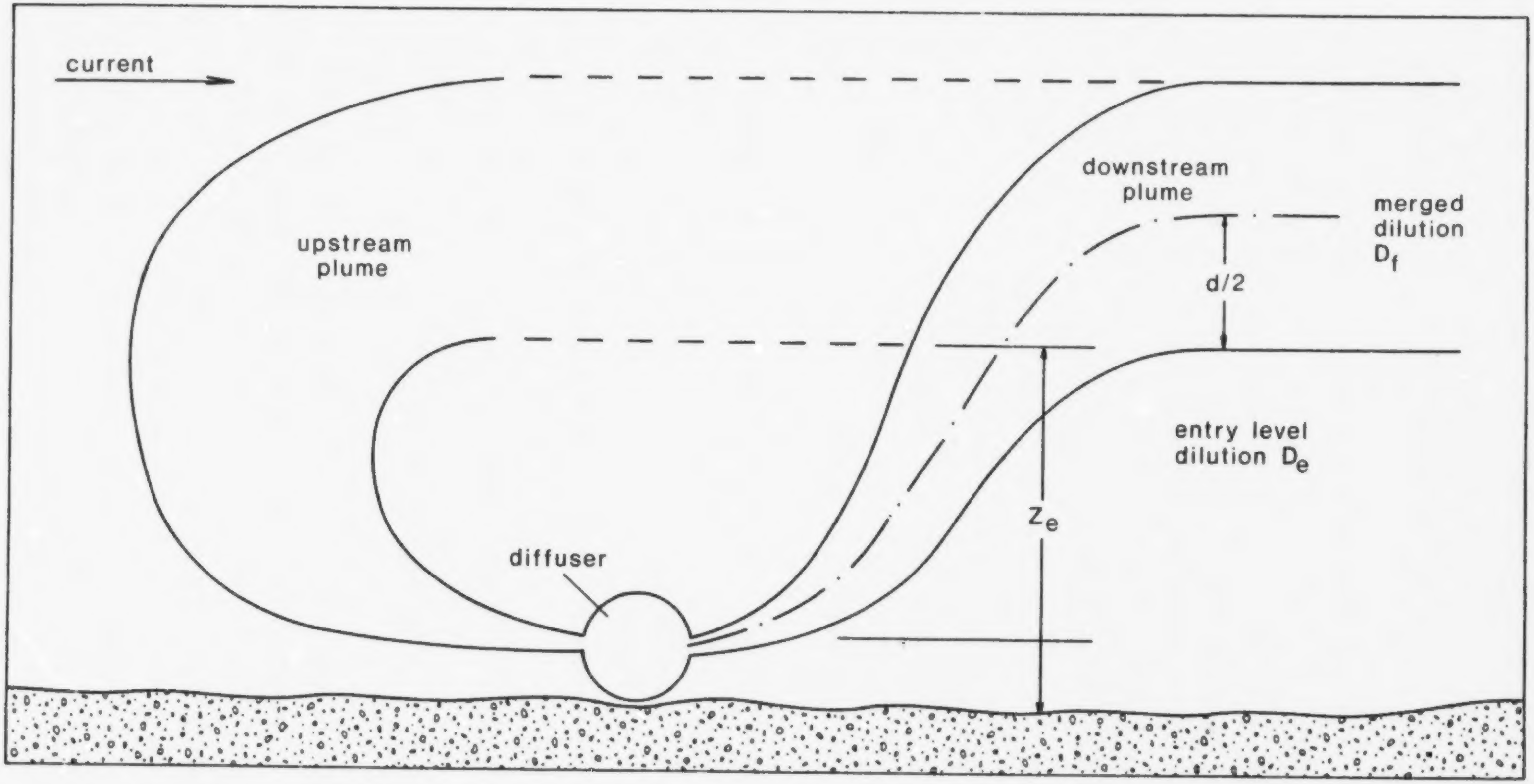


FIGURE VI-31 CROSS DIFFUSER MERGING

Given that Fr = 3, PS = 25, SP = 2000, and k = 0.1, and that identical plumes are injected into the ambient water from both sides of the diffuser. From Table 63, it is found that the dilution is 270 and the rise is 55.1 diameters. The width of the plumes may be estimated:

$$d/d_o = (\pi 270)/[4(0.1)(25)] = 85$$

(cf. the computer calculated width of 83 diameters). Therefore, the vertical distance between the ports and the plume entry level is 55.1-85/2 = 12.6 diameters, and, D_e = 15.5 as estimated from the table at rise equal to 12 diameters. D_f may now be calculated:

$$D_f = 270/[2(270) - 15.5] = 139$$

This result may have been anticipated: the dilution is effectively halved. This is the outcome whenever the entry level, Z_e, is small. In many cases, halving the dilution provided in the tables gives an adequate estimate of the overall dilution achieved by the cross diffuser merging plumes.

Example H. Given that PS = 25, SP = 200, k = 0.0, Fr = 10, and that an estimate of the centerline dilution at maximum rise is required. By consulting Table 77, it is found that the average dilution at maximum rise is 26.0. Since there is no current and virtually no merging, this value can be divided by 1.77 to obtain the centerline dilution (based on a gaussian profile, see Teeter and Baumgartner, 1979). The centerline dilution is 14.7.

With identical conditions except for port spacing of 2 instead of 25, Table 16 shows that the dilution at maximum rise is 11.6. The centerline dilution is again smaller but not by the same percentage amount. For the 3/2 power profile, similar to the gaussian, the peak-to-mean ratio in stagnant ambient and complete merging is 1.43 (Teeter and Baumgartner, 1979). Thus the centerline dilution may be found to be 8.1.

The peak-to-mean ratios given above are flow-weighted and are obtained through a straightforward integration. Unfortunately the problem is not as simple when current is present because the gaussian or other arbitrary profiles of velocity are superimposed onto a non-zero average velocity. Hence, in high current, the peak-to-mean ratio for single plumes assuming the 3/2 power profile is 3.89. For merged plumes, the ratio is lower. For intermediate currents, the ratio is between the corresponding extremes depending on the degree of merging and the actual current velocity.

Fortunately, many standards and regulations - for example, the Federal 301(h) regulations - are written in terms of average dilutions. Also, repeated measurements in the field are likely to provide estimates of average concentrations before estimates of maximum concentrations are possible. Thus, the user of MERGE is normally not concerned with centerline dilutions. It is useful to remember that estimating average dilutions using centerline models involves not only the use of variable peak-to-mean ratios but also variable aspiration coefficients.

END OF EXAMPLE VI-11

6.5.3 Pollutant Concentration Following Initial Dilution

The concentration of a conservative pollutant at the completion of initial dilution is expressible as:

$$C_f = C_a + \frac{C_e - C_a}{Sa} \qquad \text{(VI-65)}$$

where

C_a = background concentration, mg/l

C_e = effluent concentration, mg/l

Sa = initial dilution (flux-averaged)

C_f = concentration at the completion of initial dilution, mg/l.

When the background level, C_a, is negligible Equation VI-65 simplifies to:

$$C_f = \frac{C_e}{Sa} \qquad \text{(VI-66)}$$

This expression can be used to predict the increased pollutant concentration above ambient, as long as the effluent concentration greatly exceeds the ambient concentration. It is interesting to note that when the effluent concentration is below ambient, the final pollutant concentration is also below ambient.

Since water quality criteria are often prescribed as maximum values not to be exceeded following initial dilution, it is useful to rearrange Equation VI-65 to express the maximum allowable effluent concentration as follows:

$$(C_e)_{max} = C_a + (Sa)_{min} (C_c - C_a) \qquad \text{(VI-67)}$$

where

$(C_e)_{max}$ = maximum allowable effluent concentration such that water quality criteria are not exceeded.

C_c = applicable water quality criterion

$(Sa)_{min}$ = minimum expected initial dilution

Since initial dilution is a function of discharge and receiving water characteristics, as discussed in detail in Section 6.5.2, finding an appropriate "minimum" initial dilution is not a trivial problem. Most often, initial dilutions are lowest when density stratification is greatest. For a given stratification profile, dilutions generally decrease at lower ambient current speeds and higher effluent flow rates. Based on expected critical conditions in the vicinity of the discharge, the tables in Appendix G can be used to predict $(Sa)_{min}$.

EXAMPLE VI-12

Analysis of the effluent wastewater from a treatment plant discharging into a large west coast estuary revealed that the effluent contained a number of priority pollutants. A few of the pollutants and their measured concentrations are shown below.

	Concentrations (μg/l)		Criterion Level
Priority Pollutant	Dry Weather	Wet Weather	(μg/l)
copper	32.3	61.9	4.0
zinc	33.0	180.0	58.0
mercury	not detected	3.5	0.025
lindane	8.6	not detected	0.16

The critical initial dilution has been determined to be 30. If the criterion levels are designed to be complied with at the completion of initial dilution, determine if the criteria for the four priority pollutants are contravened.

A cursory review of the tabulations above shows that all detected effluent pollutant concentrations (i.e. undiluted concentrations) exceed the criteria levels, other than zinc during dry weather flow conditions. Hence if initial dilutions were to become low enough, each of the four priority pollutants could violate water quality criterion for either dry or wet weather conditions.

Using the minimum initial dilution of 30, the final pollutant levels can be predicted using Equation VI-66, by assuming background levels are neglible. The final pollutant levels compared with the criterion levels are shown below.

Priority Pollutant	Final Concentrations (µg/l) Dry Weather	Wet Weather	Criterion Level (µg/l)
copper	1.1	2.1	4.0
zinc	1.1	6.0	58.0
mercury	-	0.1	0.025
lindane	0.3	-	0.16

Both mercury and lindane violate the criteria while copper and zinc do not. However, copper levels are sufficiently close to the criterion of 4.0 µg/l to warrant further attention.

END OF EXAMPLE VI-12

6.5.4 pH Following Initial Dilution

The pH standard governing wastewater discharges into estuarine or coastal waters is usually quite strict. Typically, state standards require that the pH following initial dilution not deviate by more than 0.2 units from background. A step by step approach is presented here that can be used to determine whether a discharge will comply with a standard of this type.

Step 1. The following input data are required:

Sa = initial dilution

Alk_a = alkalinity of receiving water, eq/l

Alk_e = alkalinity of effluent wastewater, eq/l

pH_a = pH of receiving water

pH_e = pH of effluent wastewater

$K_{a,1}$, ${}^{c}K_{a,1}$ = equilibrium constant for dissociation of carbonic acid in wastewater and receiving water, respectively (first acidity constants)

$K_{a,2}$, ${}^{c}K_{a,2}$ = equilibrium constant for dissociation of bicarbonate in wastewater and receiving water, respectively (second acidity constants)

K_w, ${}^{c}K_w$ = ion product for wastewater and receiving water, respectively.

Table VI-21 shows values of the equilibrium constants and ion product of water. For seawater, typical values of pH and alkalinity are 8.3 units and 2.3 meq/l, respectively.

TABLE VI-21

VALUES OF EQUILIBRIUM CONSTANTS AND ION PRODUCT OF WATER AS A FUNCTION OF TEMPERATURE FOR FRESHWATER AND SALT WATER

	$-\log K_{a,1}$		$-\log K_{a,2}$	
Temperature, °C	Freshwater	Seawater	Freshwater	Seawater
5	6.52	6.00	10.56	9.23
10	6.46	5.97	10.49	9.17
15	6.42	5.94	10.43	9.12
20	6.38	5.91	10.38	9.06
25	6.35	5.84	10.33	8.99

	$-\log K_w$	
Temperature, °C	Freshwater	Seawater
5	14.63	14.03
15	14.35	13.60
20	14.17	13.40
25	14.00	13.20

Step 2. Calculate the total inorganic carbon concentrations in the effluent wastewater (C_{te}) and receiving water (C_{ta}):

$$C_{te} = \frac{Alk_e - \frac{K_w}{[H^+]_e} + [H^+]_e}{(\alpha_1 + 2\alpha_2)_e} \qquad \text{(VI-68)}$$

and

$$C_{t_a} = \frac{AlK_a - \frac{{}^cK_w}{[H^+]_a} + [H^+]_a}{(\alpha_1 + 2\alpha_2)_a} \qquad \text{(VI-69)}$$

where

$$\alpha_1 = \frac{[H^+]\, K_{a,1}}{[H^+]^2 + [H^+]\, K_{a,1} + K_{a,1} K_{a,2}} \qquad \text{(VI-70)}$$

$$\alpha_2 = \frac{K_{a,1}\ k_{a,2}}{[H^+]^2 + [H^+]\, K_{a,1} + K_{a,1}\, K_{a,2}} \qquad \text{(VI-71)}$$

Note: ${}^cK_{a,1}$ and ${}^cK_{a,2}$ are used in α_1 and α_2 to calculate C_{ta}.

Step 3. Calculate the akalinity (Alk_f) and total inorganic carbon (C_{tf}) at the completion of initial dilution:

$$Alk_f = Alk_a + \frac{Alk_e - Alk_a}{Sa} \qquad \text{(VI-72)}$$

$$C_{t_f} = C_{t_a} + \frac{C_{t_e} - C_{t_a}}{Sa} \qquad \text{(VI-73)}$$

Step 4. Express the final alkalinity as:

$$Alk_f = C_{t_f} (\alpha_1 + 2\alpha_2)_f + \frac{{}^{c}K_W}{[H^+]_f} - [H^+]_f \qquad \text{(VI-74)}$$

Rather than solving for $[H^+]_f$ directly in Equation VI-74, it is easier to calculate Alk_f in Equation VI-72 for a range of $[H^+]$ values, until the alkalinities computed from Equations VI-72 and VI-74 match.

In most cases pH_f will not differ from the ambient pH by more than 0.1 to 0.3 units. Consequently it is usually most expeditious to begin by assuming $pH_f = pH_a$. If $pH_e > pH_a$, then each subsequent calculation should be at 0.1 pH units higher than pH_a. If $pH_e < pH_a$, each subsequent calculation should be 0.1 pH units lower than pH_a.

For typical values of wastewater alkalinity (2.0 meq/l) and receiving water alkalinity (2.3 meq/l), the pH at the completion of initial dilution can be tabulated for selected values of effluent pH, initial dilution, and water temperature. Table VI-22 shows the results, which can be used to provide a quick indication of whether the water quality criterion for pH is violated.

TABLE VI-22

ESTIMATED pH VALUES AFTER INITIAL DILUTION

Seawater Temp. °C	5°C					15°C					25°C				
Seawater pH	Initial Dilution 10	25	50	75	100	Initial Dilution 10	25	50	75	100	Initial Dilution 10	25	50	75	100
Effluent pH = 6.0 Alk = 0.1															
7.0	6.94	6.97	6.98	6.98	6.99	6.95	6.97	6.98	6.99	6.99	6.95	6.98	6.99	6.99	6.99
7.5	7.37	7.44	7.47	7.47	7.48	7.40	7.45	7.47	7.43	7.48	7.42	7.46	7.48	7.48	7.49
7.7	7.56	7.64	7.67	7.67	7.68	7.59	7.65	7.67	7.68	7.68	7.62	7.66	7.68	7.68	7.69
8.0	7.88	7.95	7.97	7.97	7.98	7.91	7.96	7.98	7.98	7.99	7.94	7.97	7.98	7.99	7.99
8.3	8.21	8.26	8.28	8.28	8.29	8.24	8.27	8.28	8.29	8.29	8.25	8.25	8.29	8.29	8.29
8.5	8.43	8.47	8.48	8.48	8.49	8.45	8.48	8.49	8.49	8.49	8.46	8.48	8.49	8.49	8.49
Effluent pH = 6.0 Alk = 0.6															
7.0	6.74	6.87	6.93	6.95	6.96	6.77	6.89	6.94	6.96	6.97	6.77	6.89	6.94	6.96	6.97
7.5	6.98	7.23	7.35	7.40	7.42	7.03	7.27	7.38	7.42	7.44	7.08	7.31	7.40	7.43	7.45
7.7	7.07	7.39	7.53	7.59	7.61	7.16	7.45	7.57	7.61	7.63	7.24	7.51	7.60	7.64	7.65
8.0	7.27	7.70	7.85	7.90	7.93	7.44	7.79	7.90	7.93	7.95	7.60	7.85	7.93	7.95	7.96
8.3	7.66	8.08	8.20	8.23	8.25	7.89	8.15	8.23	8.25	8.26	8.02	8.19	8.24	8.26	8.27
8.5	8.01	8.33	8.42	8.44	8.46	8.18	8.38	8.44	8.46	8.47	8.27	8.41	8.45	8.47	8.47
Effluent pH = 6.0 Alk = 1.0															
7.0	6.63	6.81	6.89	6.92	6.94	6.66	6.83	6.90	6.93	6.95	6.67	6.84	6.91	6.93	6.95
7.5	6.80	7.10	7.27	7.34	7.37	6.86	7.15	7.31	7.36	7.39	6.90	7.20	7.33	7.38	7.41
7.7	6.86	7.23	7.43	7.52	7.56	6.94	7.30	7.49	7.56	7.59	7.01	7.38	7.53	7.58	7.61
8.0	6.98	7.48	7.75	7.83	7.87	7.12	7.63	7.82	7.88	7.91	7.29	7.73	7.86	7.90	7.92
8.3	7.21	7.91	8.12	8.18	8.21	7.51	8.04	8.17	8.21	8.23	7.76	8.10	8.19	8.22	8.23
8.5	7.51	8.20	8.35	8.40	8.42	7.89	8.28	8.39	8.42	8.44	8.06	8.32	8.40	8.42	8.43
Effluent pH = 6.0 Alk = 2.0															
7.0	6.45	6.68	6.81	6.86	6.89	6.48	6.71	6.83	6.88	6.90	6.50	6.72	6.84	6.88	6.91
7.5	6.55	6.88	7.11	7.21	7.27	6.60	6.94	7.16	7.25	7.31	6.64	6.99	7.20	7.29	7.34
7.7	6.58	6.96	7.23	7.36	7.43	7.64	7.04	7.31	7.43	7.50	6.70	7.12	7.39	7.49	7.54
8.0	6.64	7.11	7.49	7.66	7.75	6.73	7.28	7.65	7.77	7.83	6.93	7.45	7.75	7.84	7.88
8.3	6.73	7.41	7.91	8.06	8.12	6.89	7.73	8.06	8.14	8.18	7.11	7.91	8.12	8.18	8.21
8.5	6.83	7.78	8.20	8.31	8.36	7.10	8.07	8.30	8.37	8.40	7.48	8.18	8.35	8.40	8.42
Effluent pH = 6.5 Alk = 0.5															
7.0	6.92	6.96	6.98	6.98	6.99	6.93	6.97	6.98	6.98	6.99	6.93	6.97	6.98	6.98	6.99
7.5	7.32	7.42	7.45	7.47	7.47	7.34	7.43	7.46	7.47	7.48	7.37	7.44	7.46	7.47	7.48
7.7	7.49	7.61	7.65	7.66	7.67	7.53	7.63	7.66	7.67	7.67	7.56	7.64	7.66	7.67	7.67
8.0	7.80	7.92	7.96	7.97	7.97	7.85	7.94	7.96	7.97	7.98	7.88	7.94	7.96	7.97	7.97
8.3	8.15	8.24	8.26	8.27	8.28	8.19	8.25	8.27	8.27	8.28	8.20	8.25	8.26	8.27	8.27
8.5	8.38	8.45	8.47	8.48	8.48	8.40	8.45	8.47	8.47	8.48	8.40	8.44	8.46	8.46	8.46
Effluent pH = 6.5 Alk = 1.0															
7.0	6.85	6.93	6.96	6.97	6.98	6.87	6.94	6.97	6.98	6.98	6.88	6.94	6.97	6.98	6.98
7.5	7.18	7.35	7.42	7.44	7.46	7.22	7.37	7.43	7.45	7.46	7.26	7.40	7.45	7.46	7.47
7.7	7.31	7.53	7.61	7.64	7.65	7.39	7.57	7.63	7.65	7.66	7.45	7.60	7.65	7.66	7.67
8.0	7.60	7.84	7.92	7.95	7.96	7.72	7.89	7.94	7.96	7.97	7.80	7.92	7.96	7.97	7.98
8.3	8.00	8.19	8.24	8.26	8.27	8.09	8.22	8.26	8.27	8.28	8.14	8.24	8.27	8.28	8.28
8.5	8.26	8.41	8.45	8.47	8.47	8.33	8.43	8.46	8.47	8.48	8.36	8.44	8.47	8.48	8.48
Effluent pH = 6.5 Alk = 2.0															
7.0	6.75	6.88	6.93	6.95	6.96	6.78	6.89	6.94	6.96	6.97	6.79	6.90	6.94	6.96	6.97
7.5	6.99	7.23	7.35	7.39	7.42	7.04	7.27	7.37	7.41	7.43	7.08	7.30	7.39	7.42	7.44
7.7	7.07	7.38	7.53	7.58	7.61	7.15	7.44	7.56	7.61	7.63	7.23	7.49	7.59	7.62	7.64
8.0	7.25	7.67	7.84	7.89	7.92	7.41	7.77	7.88	7.92	7.94	7.55	7.82	7.90	7.93	7.94
8.3	7.61	8.06	8.18	8.22	8.24	7.84	8.13	8.21	8.23	8.25	7.96	8.16	8.22	8.24	8.25
8.5	7.95	8.30	8.40	8.43	8.45	8.12	8.35	8.42	8.44	8.45	8.20	8.36	8.42	8.43	8.44
Effluent pH = 9.0 Alk = 2.0															
7.0	7.03	7.01	7.00	7.00	7.00	7.04	7.01	7.00	7.00	7.00	7.04	7.01	7.00	7.00	7.00
7.5	7.52	7.51	7.50	7.50	7.50	7.51	7.50	7.50	7.50	7.50	7.51	7.50	7.50	7.50	7.50
7.7	7.71	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70
8.0	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
8.3	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30
8.5	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
Effluent pH = 9.0 Alk = 4.0															
7.0	7.07	7.03	7.01	7.01	7.00	7.08	7.03	7.01	7.01	7.00	7.08	7.03	7.01	7.01	7.00
7.5	7.54	7.51	7.50	7.50	7.50	7.54	7.51	7.50	7.50	7.50	7.53	7.51	7.50	7.50	7.50
7.7	7.71	7.70	7.70	7.70	7.70	7.71	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70
8.0	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
8.3	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30
8.5	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
Effluent pH = 9.0 Alk = 6.0															
7.0	7.10	7.04	7.02	7.01	7.01	7.11	7.04	7.02	7.01	7.01	7.11	7.05	7.02	7.01	7.01
7.5	7.56	7.52	7.51	7.50	7.50	7.56	7.52	7.51	7.50	7.50	7.54	7.51	7.50	7.50	7.50
7.7	7.72	7.71	7.70	7.70	7.70	7.71	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70
8.0	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
8.3	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30
8.5	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50

Note: Values are shown to 2 decimal places to allow interpolation but should be rounded to 1 decimal place for comparison to standards.

EXAMPLE VI-13

A wastewater treatment plant receives alkaline waste process water, and because of the low level of treatment received in the plant, effluent pH values as high as 11.1 units have been observed. The effluent wastewater is discharged into a water body where the pH standard permits a 0.2 unit deviation from ambient at the completion of initial dilution. Determine if the standard is violated by the discharge. The required pertinent data are:

pH_a = 8.3

Alk_a = 2.3 meq/l

Alk_e = 2.0 meq/l

${}^cK_w$ = 6.3×10^{-14}, for the ambient water

K_w = 10^{-7} , for the wastewater

${}^cK_{a,1}$ = 8×10^{-7},for the ambient water

$K_{a,1}$ = 5×10^{-7}, for the wastewater

${}^cK_{a,2}$ = 4.68×10^{-10}, for the ambient water

$K_{a,2}$ = 0.5×10^{-10}, for the wastewater

Sa = 20

The dissociation constants for the wastewater, α_1, and α_2, are:

$$\alpha_1 = \frac{10^{-11.1} \times 5 \times 10^{-7}}{(10^{-11.1})^2 + 10^{-11.1} \times 5 \times 10^{-7} + 5 \times 10^{-7} \times 0.5 \times 10^{-10}} = .137$$

$$\alpha_2 = \frac{5 \times 10^{-7} \times 0.5 \times 10^{-10}}{(10^{-11.1})^2 + 10^{-11.1} \times 5 + 10^{-7} + 5 \times 10^{-7} \times 0.5 \times 10^{-10}} = .863$$

The total inorganic carbon of the wastewater is:

$$C_{t_e} = \frac{.002 - \dfrac{10^{-14}}{10^{-11.1}} + 10^{-11.1}}{0.137 + 2 \times .863} = 0.000398 \text{ mole/l}$$

The dissociation constants for the ambient water are:

$$\alpha_1 = \frac{10^{-8.3} \times 8 + 10^{-7}}{(10^{-8.3})^2 + 10^{-8.3} \times 8 \times 10^{-7} + 8 \times 10^{-7} \times 4.68 \times 10^{-10}} = 0.909$$

and

$$\alpha_2 = 0.085$$

The total inorganic carbon content is:

$$C_{t_a} = \frac{0.0023 - \dfrac{6.3 \times 10^{-14}}{10^{-8.3}} + 10^{-8.3}}{.909 + 2 \times 0.085} = .00212 \text{ mole/l}$$

The final alkalinity and inorganic carbon are:

$$Alk_f = 0.0023 + \frac{0.002 - 0.0023}{20} = 0.00229 \text{ eq/l}$$

$$C_{t_f} = 0.00212 + \frac{0.000398 - 0.00212}{20} = 0.0020 \text{ mole/l}$$

Using Equation VI-74, the alkalinity is calculated for the range of pH values tabulated below, beginning at 8.3 and incrementing by 0.1 units.

pH	Alkalinity, eq/l
8.3	0.00217
8.4	0.00222
8.5	0.00228
8.6	not needed
8.7	not needed
8.8	not needed

The actual and calculated alkalinities match at a pH barely exceeding 8.5. Since this slightly is more than 0.2 units above ambient, the pH standard is violated. The pH problem that results from this discharge could be mitigated in a number of ways, such as increasing initial dilution, or by treating the wastewater in order to lower the effluent pH.

END OF EXAMPLE VI-13

6.5.5 Dissolved Oxygen Concentration Following Initial Dilution

Dissolved oxygen standards in estuarine and coastal waters can be quite stringent. For example, the California Ocean Plan (State Water Resources Control Board, 1978) specifies that:

> "The dissolved oxygen concentration shall not at any time be depressed more than 10 percent from that which occurs naturally, as the result of the discharge of oxygen demanding waste materials."

Since dissolved oxygen concentrations can naturally range as low as 4.0 to 5.0 mg/l at certain times of the year in estuarine or coastal waters, allowable depletions under these conditions are only 0.4 to 0.5 mg/l.

The dissolved oxygen concentration following initial dilution can be predicted using the following expression:

$$DO_f = \overline{DO}_a + \left[\frac{DO_e - IDOD - \overline{DO}_a}{Sa} \right] \quad \text{(VI-75)}$$

where

DO_f = final dissolved oxygen concentration of receiving water at the plume's trapping level, mg/l

$\overline{DO}_a$ = ambient dissolved oxygen concentration averaged from the diffuser to the trapping level, mg/l

DO_e = dissolved oxygen of effluent, mg/l

IDOD = immediate dissolved oxygen demand, mg/l

Sa = initial dilution.

The immediate dissolved oxygen demand represents the oxygen demand of reduced substances which are rapidly oxidized during initial dilution (e.g. sulfides to sulfates). The procedure for determining IDOD is found in standard methods (APHA, 1976). IDOD values are often between 1 and 5 mg/l, but can be considerably higher. When the effluent dissolved oxygen concentration is 0.0 mg/l and IDOD is negligible (which is a common situation), Equation VI-75 simplifies to:

$$DO_f = \overline{DO}_a \left(1 - \frac{1}{Sa} \right) \quad \text{(VI-76)}$$

The ambient dissolved oxygen concentration which appears in Equations VI-75 and VI-76 is the concentration in the water column averaged between the location of the diffuser and the trapping level, while the final dissolved oxygen concentration is referenced to the plume's trapping level.

The dissolved oxygen concentration can change significantly over depth, depending on the estuary or coastal system as well as on seasonal influences (e.g. upwelling). As the plume rises during initial dilution, water from deeper parts of the water column is entrained into the plume and advected to the plume's trapping level. If the dissolved oxygen concentration is much lower in the bottom of the water column than in the top, the low dissolved oxygen water is advected to a region formerly occupied by water containing higher concentrations of dissolved oxygen, and then a "pseudo" dissolved oxygen depletion results, solely caused by entrainment and advection and not consumption of oxygen-demanding material. The following example illustrates this process.

EXAMPLE VI-14

Puget Sound, located in the northwest corner of the state of Washington, is a glacially carved, fjord-type estuary. The average depth of water is about 100 m (330 ft). During periods of upwelling, low dissolved oxygen water enters the estuary at depth and produces a vertical dissolved oxygen gradient throughout much of the estuary. In Commencement Bay, near Tacoma, dissolved oxygen profiles similar to the one shown in Table VI-23 have been observed. Suppose the trapping level is 43 ft (13 m) above the bottom and the minimum initial dilution is 28. Find the final dissolved oxygen concentration and calculate the percent depletion.

The dissolved oxygen concentration varies significantly over depth, from 5.0 mg/l at the bottom to 7.8 mg/l at the water's surface. The average concentration over the plume's trapping level is:

$$\frac{5.0 + 6.1}{2} = 5.6 \text{ mg/l}$$

Using Equation VI-76, the final dissolved oxygen concentration at the trapping level is:

$$DO_f = 5.6 \left(1 - \frac{1}{28} \right) = 5.4 \text{ mg/l}$$

TABLE VI-23

DISSOLVED OXYGEN PROFILE IN COMMENCEMENT BAY, WASHINGTON

Depth ft(m)	Temperature, °C	Dissolved Oxygen, mg/l
0 (0)	14.0	7.8
3 (1)	12.0	7.7
7 (2)	12.0	7.6
10 (3)	11.7	7.4
16 (5)	11.7	7.2
23 (7)	11.7	7.0
33 (10)	12.5	6.8
49 (15)	13.5	6.5
66 (20)	11.5	6.1
98 (30)	11.5	5.3
108 (33)	11.5	5.0

Compared to the ambient concentration at the trapping level (6.1 mg/l), the percent depletion is:

$$\frac{6.1 - 5.4}{6.1} \times 100 = 11 \text{ percent}$$

Compared to the average over the height of rise, the percent depletion is only:

$$\frac{5.6 - 5.4}{5.6} \times 100 = 4 \text{ percent}$$

END OF EXAMPLE VI-14

In contrast to the deep estuaries on the west coast of the United States, those on the east coast are quite shallow. In the Chesapeake Bay, the largest east coast estuary, water depths are often in the 20- to 30-ft (6 to 9 m) range, with channels as deep as 60 to 90ft (18 to 27 m) in places. Because of the shallow water depths, initial dilution is often limited by the depth of the water and can be 10 or less at times of low ambient current velocity.

6.5.6 Far Field Dilution and Pollutant Distribution

After the initial dilution process has been completed, the wastefield becomes further diluted as it migrates away from the ZID. Since concentrations of coliform organisms are often required not to exceed certain specified values at sensitive locations (e.g. public bathing beaches), a tool is needed to predict coliform (or other pollutant) levels as a function of distance from the ZID. This can be accomplished by solving the following expression:

$$u \frac{\partial C}{\partial x} = \varepsilon_y \frac{\partial^2 C}{\partial y^2} - kC \qquad \text{(VI-77)}$$

where

C = pollutant concentration

u = current speed

ε_y = lateral turbulent diffusion coefficient

k = pollutant decay rate.

Figure VI-32 shows how the sewage field spreads laterally as a function of distance from the ZID. The concentration within the wastefield, $C(x,y)$, depends on both x and y, with the maximum concentrations occurring at $y = 0$, for any x value.

It is the maximum concentration $C(x, y = 0)$ which is of interest here. Solving Equation VI-77, the maximum concentration as a function of distance x is:

$$C = C_a + \frac{C_f - C_a}{D_s} \exp\left(- \frac{kx}{u}\right) \qquad \text{(VI-78)}$$

where

D_s = dilution attained subsequent to the initial dilution and is a function of travel time

and all other symbols have been previously defined.

The subsequent dilution is unity when $x = 0$ (i.e. at the completion of initial dilution), so $C = C_f$ at $x = 0$, as required. In many instances, the background concentration is negligible, so that Equation VI-78 simplifies to:

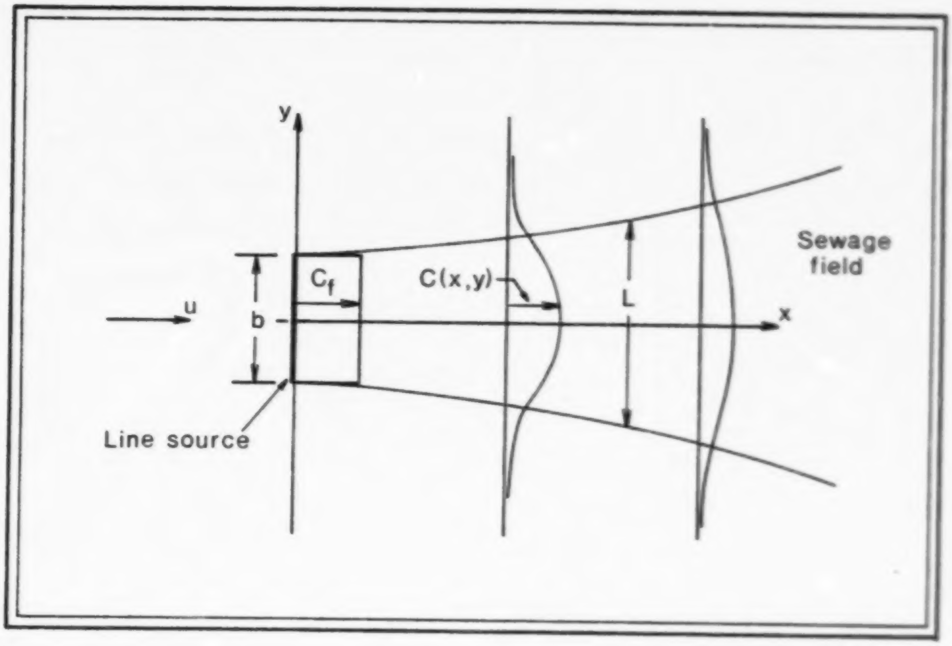


FIGURE VI-32 PLAN VIEW OF SPREADING SEWAGE FIELD

$$C = \frac{C_f}{D_s} \exp(-kt) \tag{VI-79}$$

Subsequent dilution gradually increases as the wastefield travels away from the ZID and depends on mixing caused by turbulence, shear flows, and wind stresses. Often, dilution caused by lateral entrainment of ambient water greatly exceeds that caused by vertical entrainment. This is assumed to be the case here.

In open coastal areas, the lateral dispersion coefficient is often predicted using the so-called 4/3 law (Brooks, 1960), where the diffusion coefficient increases as the 4/3 power of the wastefield width. In mathematical form:

$$\varepsilon = \varepsilon_o \left(\frac{L}{b}\right)^{4/3} \tag{VI-80}$$

where

ε_o = diffusion coefficient when L = b

L = width of sewage field at any distance from the ZID

b = initial width of sewage field.

The initial diffusion coefficient can be predicted from:

$$\varepsilon_o = 0.001b^{4/3} \tag{VI-81}$$

where

ε_o = initial diffusion coefficient, ft^2/sec b = initial width of sewage field, ft.

Based on Equation VI-80, the centerline dilution, D_s, is given by:

$$D_s = \left[\operatorname{erf} \left(\frac{1.5}{\left(1 + \frac{8 \varepsilon_o t}{b^2}\right)^3 - 1} \right)^{1/2} \right]^{-1} \qquad \text{(VI-82)}$$

where

t = travel time

and erf denotes the error function.

The 4/3 law is not always applicable and in confined estuaries might overestimate the diffusion coefficient. Under these circumstances, it is more conservative to assume the diffusion coefficient is a constant. Equation VI-81 can be used to estimate the constant diffusion coefficient, unless the user has better data. Under these circumstances, the subsequent dilution is expressible as:

$$D_s = \left[\operatorname{erf} \left(\frac{b^2}{16 \varepsilon_o t} \right)^{1/2} \right]^{-1} \qquad \text{(VI-83)}$$

Equations VI-82 and VI-83 are cumbersome to use, especially if repeated applications are needed. To facilitate predicting subsequent dilutions, values of D_s are tabulated in Table VI-24 for different initial widths (b) and travel times (t). The initial sewage field widths range from 10 to 5,000 feet and travel times range from 0.5 to 96 hours.

TABLE VI-24

SUBSEQUENT DILUTIONS* FOR VARIOUS INITIAL
FIELD WIDTHS AND TRAVEL TIMES

	Initial Field Width (ft)					
Travel Time(hr)	10	50	100	500	1000	5000
0.5	2.3/ 5.5	1.5/ 2.0	1.3/ 1.6	1.0/ 1.1	1.0/ 1.0	1.0/ 1.0
1.0	3.1/ 13.	2.0/ 3.9	1.6/ 2.6	1.2/ 1.3	1.1/ 1.1	1.0/ 1.0
2.0	4.3/ 32.	2.7/ 8.5	2.2/ 5.1	1.4/ 1.9	1.2/ 1.5	1.0/ 1.0
4.0	6.1/ 85.	3.7/ 21.	3.0/ 11.	1.9/ 3.5	1.5/ 2.3	1.1/ 1.2
8.0	8.5/>100.	5.2/ 53.	4.1/ 29.	2.5/ 7.3	2.0/ 4.4	1.4/ 1.7
12.	10. />100.	6.3/ 95.	5.1/ 50.	3.0/ 12.	2.4/ 6.8	1.6/ 2.3
24.	15. />100.	8.9/>100.	7.1/ 100.	4.2/ 30.	3.4/ 16.	2.1/ 4.4
48.	21. />100.	13. />100.	10. />100.	5.9/ 80.	4.7/ 41.	2.8/10.
72.	26. />100.	15. />100.	12. />100.	7.3/>100.	5.8/ 73	3.4/17.
96.	29. />100.	18. />100.	14. />100.	8.4/>100.	6.6/100.	3.9/24.

---

[*] The dilutions are entered in the table as N_1/N_2, where N_1 is the dilution assuming a constant diffusion coefficient, and N_2 is the dilution assuming the 4/3 law.

The dilutions presented in the table reveal that as the initial field width increases, the subsequent dilution decreases for a given travel time. For a wider wastefield, a larger time is required to entrain ambient water into the center of the wastefield, so dilutions are lower. This illustrates that a tradeoff exists between large diffusers where initial dilution is high but subsequent dilution low, and small diffusers where initial dilution is low and subsequent dilution high.

The table also reveals that the predicted dilutions are significantly different, depending on whether Equation VI-82 or VI-83 is used. In many cases likely to be evaluated by users of this document, the 4/3 law might overestimate subsequent dilution, even if the outfall is in coastal waters. To attain the subsequent dilutions predicted by the 4/3 law at large travel times, a significant amount of dilution water must be available. Since many outfalls, particularly small ones, are often not too far from shore, the entrainment rate of dilution water can be restricted by the presence of the shoreline and the depth of the water. The wastefield from diffusers located further offshore might entrain water at a rate corresponding to the 4/3 law for an initial period of time. As the wastefield widens significantly, the rate of entrainment could decrease, and the 4/3 law no longer obeyed.

When travel times are small (e.g. 12 hours or less), there is less discrepancy between the two methods of calculating subsequent dilution, except for the very small initial wastefield widths.

EXAMPLE VI-15

Figure VI-33 shows an outfall which extends about one mile offshore. At the end of the outfall is a multiport diffuser, 800 feet in length. Occassionally, fecal coliform bacteria counts as high as 10,000 MPN/100 ml have been detected in the effluent of the treatment plant.

The allowable fecal coliform level at the shellfish harvesting area inshore of the diffuser is 70 MPN/100 m. Typically, the ambient current is parallel to shore so that effluent is not carried onshore. However, when

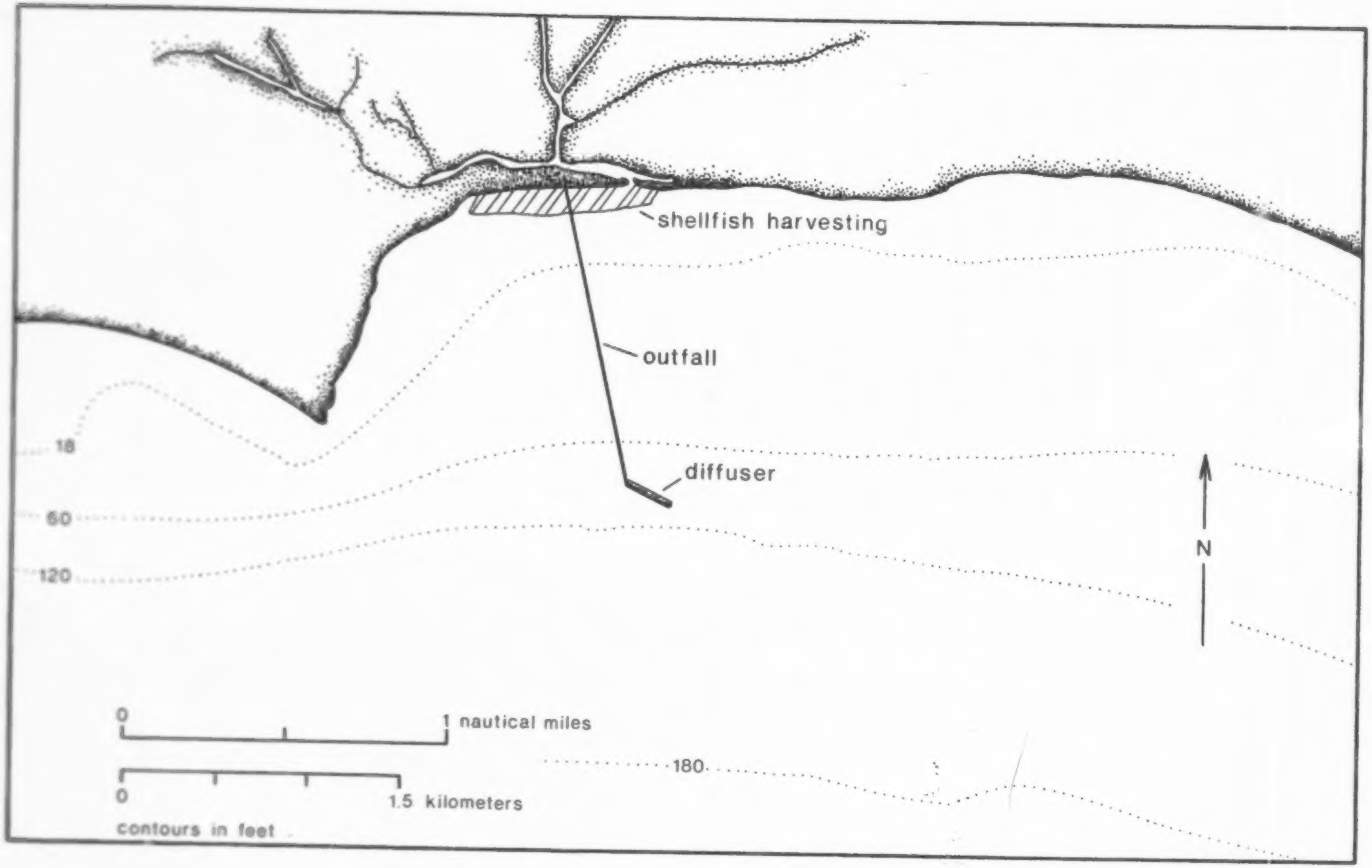


FIGURE VI-33 OUTFALL LOCATION, SHELLFISH HARVESTING AREA, AND ENVIRONS

wind conditions are right, onshore transport has been observed, and the sustained transport velocity is 4 cm/sec (0.13 ft/sec). Determine whether the coliform standard is likely to be violated or not. Other information needed are:

- coliform decay rate = 1.0/day
- minimum initial dilution = 35.

The width of the diffuser is 800 feet and will be used as the initial field width. Note, however, that the diffuser is not exactly perpendicular to shore, so that the initial field width is probably less than 800 feet in the travel direction. Using 800 feet is conservative because subsequent dilution will be somewhat lower under this assumption.

The coliform count following initial dilution is, using Equation VI-76:

$$C_f = \frac{10000}{35} = 290 \text{ MPN/100 ml}$$

The travel time to the shore is:

$$\frac{5280}{0.13 \times 3600} = 11 \text{ hours}$$

Interpolating from Table VI-24, the subsequent dilution is about 2.6. Using Equation VI-79, the coliform concentration at the shoreline is:

$$C = \frac{290}{2.6} \exp\left[- 1 \times \frac{11}{24}\right] = 70 \text{ MPN/100 ml}$$

The predicted coliform count is equal to the water quality standard. Since the subsequent dilution was conservatively estimated, it is possible that actual coliform counts will be less than 70 MPN/100 ml. However, the prediction does indicate that careful monitoring of coliform levels at the shoreline is needed to see that the standard is not violated. Since shoreward transport of effluent is infrequent, sampling has to be conducted at times when the transport is shoreward; otherwise detected coliform levels might not represent worst-case conditions.

END OF EXAMPLE VI-15

6.5.7 Farfield Dissolved Oxygen Depletion

Oxygen demanding materials contained in the effluent of wastewater treatment plants can produce dissolved oxygen deficits following discharge of the effluent into receiving waters. A method will be presented here to predict the depletion following discharge from a marine outfall. The most critical cases occur when the plume and wastefield remain submerged, so that reaeration does not occur. The analysis presented here is applicable to submerged plumes only. When the wastefield is mixed uniformly across the estuary, the methods presented earlier in Section 6.4.5 are applicable.

The oxygen-demanding materials in the wastewater are the sum of the carbonaceous and nitrogenous materials (CBOD and NBOD, respectively). It is possible that the nitrogenous demand might not be exerted if a viable background population of nitrifiers is absent from the receiving water. Under these circumstances, the wastefield is likely to be dispersed before the nitrifying population can increase to numbers capable of oxidizing the NBOD. The user can perform analyses with and without NBOD exertion and then determine whether NBOD is significant or not. If it is, it is suggested that some sampling be conducted to find out whether nitrification is occurring.

The dissolved oxygen concentration in the receiving waters can be expressed as a function of travel time as follows:

$$DO(t) = DO_a + \frac{DO_f - DO_a}{D_s} - \left[\frac{L_f}{D_s}\ [1-\exp(-Kt)]\right] \qquad \text{(VI-84)}$$

where

$DO(t)$ = dissolved oxygen concentration in a submerged wastefield as a function of travel time t, mg/l

DO_a = ambient dissolved oxygen concentration, mg/l

DO_f = dissolved oxygen concentration following initial dilution (see Equation VI-75)

k = BOD decay rate

L_f = ultimate BOD concentration above ambient at the completion of initial dilution

D_s = subsequent centerline dilution

Equation VI-84 expresses the dissolved oxygen deficit which arises due to an initial deficit at the completion of initial dilution (DO_f-DO_a) plus that caused by elevated BOD levels in the water column (L_f). The elevated BOD level is either the CBOD or sum of CBOD and NBOD. The initial dissolved oxygen deficit tends to decrease at longer and longer travel times because subsequent dilution increases. However, BOD is being exerted simultaneously and tends to cause the dissolved oxygen level to drop. Depending on the particular case being analyzed, one influence can dominate the other over a range of travel times so that a minimum dissolved oxygen level can occur either immediately following initial dilution, or at a subsequent travel time. The following example illustrates both cases.

EXAMPLE VI-16

A municipal wastewater treatment plant discharges its effluent through an outfall and diffuser system. The maximum daily CBOD value is 270 mg/l, and the critical initial dilution is 114. Limited analyses have been performed on IDOD and the results vary widely, from 0 to 66 mg/l. The length of the diffuser is 500 m (1,640 ft) and can be used as the initial sewage field width. Determine the dissolved oxygen deficit produced by the discharge, assuming the wastefield remains submerged and the ambient dissolved oxygen concentration is 7.0 mg/l.

The BOD concentration at the completion of initial dilution is:

$$\frac{270}{114} = 2.4 \text{ mg/l}, \text{BOD}_5$$

$$= 3.5 \text{ mg/l, BOD-ultimate}$$

The dissolved oxygen concentration at the completion of initial dilution is (from Equation VI-75):

$$DO_f = 7.0 + \left[\frac{0.0 - 66. - 7.0}{114}\right] = 6.4 \text{ mg/l, when IDOD} = 66$$

or

$$DO_f = 7.0 + \left[\frac{0.0 - 0.0 - 7.0}{114}\right] = 6.9 \text{ mg/l, when IDOD} = 0$$

Note that the IDOD of 66 mg/l produces a deficit of 0.6 mg/l.

Since values of IDOD vary widely due to the limited analyses, the far field oxygen depletion curves will be calculated for the following three IDOD's: 0, 40, and 66 mg/l. A BOD decay rate of 0.2/day is used. When IDOD = 66 mg/l, the following oxygen depletions are predicted:

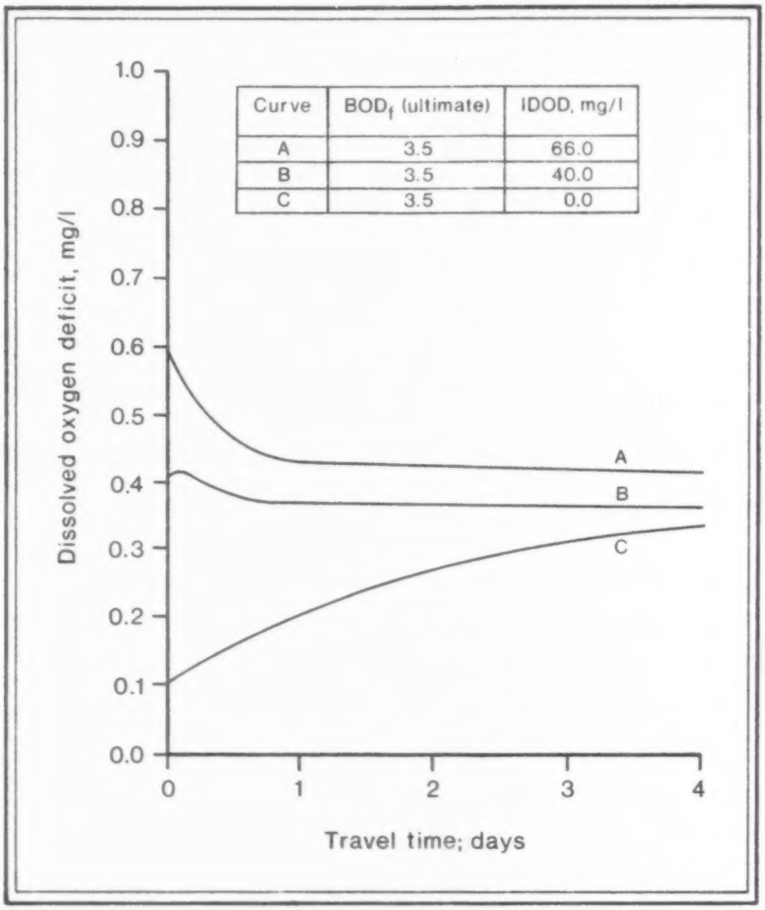
Travel Time(hr)	D_s(Table VI-24)	DO_a-DO_t (Equation VI-84)
1	1.	0.6
4	1.4	0.5
8	1.9	0.4
12	2.3	0.4
24	3.2	0.4
48	4.6	0.4
72	5.5	0.4
96	6.3	0.4

These results are plotted in Figure VI-34 (Curve A), along with the cases for IDOD = 40 mg/l (Curve B), and IDOD = 0.0 mg/l (Curve C).

When the IDOD is 66 mg/l, the maximum dissolved oxygen deficit is 0.6 mg/l and occurs at the completion of initial dilution (a travel time of 0.0 hr). Thus, the processes which occur during initial dilution are more significant than the subsequent BOD exertion. Curve C (IDOD = 0.0 mg/l) shows the opposite situation: farfield BOD exertion is primarily responsible for the maximum oxygen depletion of 0.3 mg/l. The middle curve (Curve B) shows the case when the oxygen depletion remains relatively constant over time and both the near field and farfield processes are important.

In summary, when the IDOD is above 40 mg/l, in this example the maximum oxygen depletion is controlled by the processes occurring during initial dilution. When IDOD is below 40 mg/l, BOD exertion in the far field is primarily responsible for the oxygen depletion. For primary treatment plants, IDOD values of 66 mg/l are atypical; values from 1 to 10 mg/l are much more common. Depending on whether the state dissolved oxygen standard is violated by Curve A, the user might need to make further IDOD determinations to firmly establish the true range of IDOD values.

END OF EXAMPLE VI-16



Curve	BOD_f (ultimate)	IDOD, mg/l
A	3.5	66.0
B	3.5	40.0
C	3.5	0.0

FIGURE VI-34 DISSOLVED OXYGEN DEPLETIONS VERSUS TRAVEL TIME

6.6 THERMAL POLLUTION

6.6.1 General

The presence of one or more major heat sources can have a significant impact on both the local biotic community and local water quality. As a result, consideration of significant thermal discharges by the planner is essential in any comprehensive water quality analysis. Thermal power plants account for the vast majority of both the number of thermal discharges and the total thermal load. However, some industrial processes generate significant amounts of excess heat.

The most important of the impacts of heat discharge are:

1. Ecological Effects: Water temperature increases change the productivity of planktonic and many benthic species. As a result local community structures are altered. Many of the species benefited by warmer conditions (e.g. blue green algae) may be considered to be undesirable. In addition, many species can perform certain life cycle functions only within a limited temperature range. Elevated temperatures may prevent some species from completing one or more life stages, thus disrupting the reproductive cycle and destroying the stability of the population.

2. Water Quality Effects: Figure VI-23 showed the relative effect of salinity and ambient temperature on oxygen saturation. From this figure, note that a 10° C* rise in temperature decreases the oxygen saturation concentration by 1.5 to 2.0 mg/l.

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*Such a rise is common near power plant thermal plumes.

3. Sediment Effects: Estuarine sedimentation rates are increased by increasing local water column temperature. The significance of this increase was discussed by Parker and Krenkel (1970). They concluded that not only are sedimentation rates be increased, but vertical particle size distribution, particle fall velocity, and thus bottom composition are also affected.

4. Beneficial Effects: The effects of thermal discharges are not all negative. It has been shown for example, that marine biofouling is substantially reduced in warmed waters (Parker and Krenkel, 1970). In fact, the recirculation of heated discharge through the condenser has proven to be a less expensive and equally effective method of biofouling control than chlorination for several California coastal power plants. Estuarine contact recreation potentials are increased by increasing local water temperatures, and extreme northern estuaries have reduced winter ice coverage as a result of thermal discharges.

6.6.2 Approach

A number of the algorithms which appear in this section were originally prepared by Tetra Tech, (1979) for the Electric Power Research Institute. The thermal screening approach for estuaries is composed of procedures that can be used to evaluate the following standards:

- The ΔT Criterion: The increase in temperature of water passing through the condenser must not exceed a specified maximum.

- The Maximum Discharge Temperature Criterion: The temperature of the heated effluent must not exceed a specified maximum.

- The Thermal Block Criterion: The cross-sectional area of an estuary occupied by temperatures greater than a specified value must not exceed a specified percentage of the total area.

- The Surface Area Criterion: The surface area covered by isotherms exceeding a specified temperature increment (above ambient) must not exceed a specified maximum.

- The Surface Temperature Criterion: No discharge shall cause a surface water temperature rise greater than a specified maximum above the natural temperature of the receiving waters at any time or place.

Table VI-25 presents a summary of the information needed to apply the thermal screening procedure. Data needed for the ΔT criterion and the maximum discharge temperature criterion were included earlier in the thermal screening section for rivers and are not repeated here. That the maximum discharge temperature criterion for rivers can be applied to estuaries assumes the intake temperature is near ambient, and that tidal action does not cause significantly elevated temperatures near the intake.

6.6.3 Application

The ΔT criterion and the effluent temperature criterion can be evaluated first following the procedures outlined in the river thermal screening section. The maximum allowable flow rate through the plant, which needs to be identified for use in evaluating those criteria, may not always have a readily determinable upper limit, unlike plants sited on rivers. For estuaries that are essentially tidal rivers, a fraction (say 20%) of the net freshwater flow rate might be used as an upper limit.

The remainder of the estuary physical screening procedure consists of evaluating the following three criteria: the thermal block, the isotherm surface area, and the surface water temperature criteria. Because of the complexity of the flow field in estuaries, slack tide conditions have been

TABLE VI-25

DATA NEEDED FOR ESTUARY THERMAL SCREENING

Variable	Criteria Where Variable Used	Definition	Default Value
ΔT_c	All	Temperature rise across the condenser (°F)	20
D_p	All	Diameter of discharge pipe or equivalent diameter of discharge canal (m)	--
U_p	Thermal block, surface area	Exit velocity of thermal discharge (m/s)	--
Q_p	All	Flow rate of discharge (m^3/s)	--
ΔT_{tb}	Thermal block	Temperature rise in estuary cross section that constitutes a thermal block (°F)	5
A_{tb}	Thermal block	Portion of estuarine cross-sectional area that constitutes a thermal block (m^2)	25% of the estuarine cross-sectional area
d_{tb}	Thermal block	Average depth of estuary from discharge location to ΔT_{tb} isotherm at slack tide (m)	--
R	Thermal block, surface area	Average freshwater flow rate flowing in the estuary past the power plant site (m^3/s)	$7Q_{10}$
W	Thermal block, surface area	Width of estuary at power plant site (m)	--
A_t	Thermal block	Cross-sectional area at power plant site (m^2)	--
D_l	Thermal block, surface area	Longitudinal dispersion coefficient (m^2/s)	see text discussion
K	Thermal block, surface area	Surface thermal transfer coefficient ($Btu/m^2 \cdot d \cdot °F$)	--
ρ	Thermal block, surface area, surface temperature	Average mass density of ambient water at power plant site (kg/m^3)	1000 (zero salinity)
C_p	Thermal block, surface area	Specific heat of water ($Btu/kg \cdot °F$)	22
S	Thermal block, surface area	Tidally and cross-sectionally averaged salinity (ppt. $^0/oo$	--
n	Thermal block,	Manning's n ($m^{1/6}$)	0.016 - 0.06
U_{max}	Thermal block, surface area	Maximum tidal velocity over a tidal cycle (m/s)	--
R_h	Thermal block, surface area	Hydraulic radium (cross-sectional area divided by wetted perimeter) (m)	--
ΔT_{sa}	Surface area	Isotherm associated with legal surface area constraint (°F)	4
$\bar{d}_s$	Surface area	Average depth under the surface area calculated for the surface area constraint (m)	--
A_{sa}	Surface area	Legally allowable surface area surrounded by isotherms equalling and exceeding ΔT_{sa}(m^2)	--
g	Surface temperature	Gravitational constant (m/s^2)	9.8
ρ_p	Surface temperature	Mass density of thermal effluent (kg/m^3)	--
h	Surface temperature	Depth to centerline of discharge jet (m)	--
ΔT_{st}	Surface temperature	Maximum legally allowable surface temperature produced by a submerged discharge (°F)	4
ρ_s	Surface temperature	Mass density of water at depth of submerged discharge (kg/m^3)	1000
$\frac{-d\rho}{dz}$	Surface temperature	Linear density gradient over water column depth ($kg/m^3 \cdot m$)	--

chosen as a basis for computations when possible. It is during these conditions that the effects of plume momentum and buoyancy are propogated the greatest distance across the estuary from the discharge site. It is also during slack tide that the thermal block is most likely to occur because of the absence of an ambient current that normally enhances plume entrainment of ambient water.

As the plume spreads across the estuary, the methodology assumes it to be vertically mixed. Although most plumes do not generally exhibit this behavior due to such effects as buoyancy and stratification, this approach will roughly estimate the capacity of the estuary at the power plant location to assimilate the excess heat.

In some instances, when the estuary is relatively narrow, the plume may extend across the estuary's entire width. In these cases (guidelines are given later to determine when this occurs) the near field momentum approach can be used. By using the well mixed assumption (even if the actual estuary is stratified) a lower limit on the expected temperature elevation across the estuary is obtained.

Slack tide conditions will also be used to evaluate the maximum surface temperature produced by a submerged discharge. Both vertically homogeneous and linearly stratified conditions can be evaluated.

6.6.3.1 Evaluating the Thermal Block Constraint. Based upon momentum considerations, the relationship between the ΔT_y isotherm and the distance (y) it extends from the discharge point is given by (Weigel, 1964):

$$y = \frac{y_o}{2}\left(\frac{\Delta T_c}{\Delta T_y}\right)^2 \quad , \text{ for } y \geq y_o \qquad \text{(VI-85)}$$

where

ΔT_c = temperature rise across the condenser (°F)

ΔT_y = temperature excess at a distance y from the discharge outlet (°F)

y = distance measured along the jet axis originating at the discharge point (m)

y_o = virtual source position (m)

The virtual source position is usually about two to ten times the diameter of the discharge orifice. The equivalent diameter of a discharge canal is the diameter of a circle whose cross-sectional area is the same as that of the discharge canal.

Brooks (1972) has shown that for round orifices, the virtual source position is approximately six times the orifice diameter. At the virtual discharge position ($y = y_o$) the average excess temperature is approximately 70 percent that at the discharge location.

Since one of the assumptions used in developing Equation VI-85 is that momentum is conserved along the jet axis, an upper limit on y must be established to prevent the user from seriously violating this assumption. The upper limit can be chosen to be where the plume velocity has decreased to 1 ft/sec or 0.31 meters per second. This implies that the minimum ΔT_y that can be evaluated using the equation is:

$$(\Delta T_y)_{min} = 0.3 \frac{\Delta T_c}{U_p} \tag{VI-86}$$

where

U_p = exit velocity of thermal discharge (m/s)

$(\Delta T_y)_{min}$ = minimum excess temperature that can be evaluated using Equation VI-86 (°F)

This constraint generally does not restrict practical application of Equation VI-85.

Using the value estimated by Brooks (1972) for the virtual source position, Equation VI-85 can be rewritten as:

$$y = 3D_p \left(\frac{\Delta T_c}{\Delta T_y}\right)^2 \quad , \text{ for } y \geq 6D_p \qquad \text{(VI-87)}$$

The distance, then, to the ΔT_{tb} isotherm (the isotherm establishing the thermal block) is given as:

$$y_{tb} = 3D_p \left(\frac{\Delta T_c}{\Delta T_{tb}}\right)^2 \quad , \text{for } \Delta T_{tb} \gtrsim (\Delta T_y)_{min} \qquad \text{(VI-88)}$$

The cross sectional area to the ΔT_{tb} isotherm is (assuming the plume remains vertically mixed):

$$A_c = y_{tb} \, \bar{d}_{tb} \qquad \text{(VI-89)}$$

where

A_c = cross sectional area measured out to the distance y_{tb} (m^2)

$\bar{d}_{tb}$ = average water depth over the distance y_{tb} (m)

If $A_c < A_{tb}$ (where A_{tb} is the cross sectional area that legally defines a thermal block, e.g. 25% of the total estuary cross sectional area) then a thermal block does not develop.

If the estuary is sufficiently narrow so that y_{tb} as found by Equation (VI-88) equals or exceeds the width of the estuary, the approach given above should not be used. Instead, a steady-state well mixed ΔT_{ss} can be found as follows:

$$\Delta T_{ss} = \frac{\Delta T_c \, Q_p}{\sqrt{R^2 + W \, A_t \, E_L \, K/(\rho C_p \cdot 24 \cdot 3600)}} \qquad \text{(VI-90)}$$

where

ΔT_{ss} = steady state well mixed excess temperature (°F)

In this steady state approach, ΔT_{ss} can no longer be estimated independently of the estuarine flow field characteristics. The surface transfer coefficient K can be determined by reference to the equilibrium temperature discussion in the river thermal screening section. Although the equilibrium temperature does not appear explicitly in Equation VI-90, its effect is indirectly included since K can not be determined independently of E. In the process of finding K, the ambient surface water temperature of the estuary generally should not be assumed to be at equilibrium because of the combined influence of ocean and river water (TRACOR, 1971), each of which may be at different temperatures.

The dispersion coefficient, E_L, is dependent on estuary characteristics. A value obtained from past studies in the vicinity of the power plant site should be used if possible. Alternatively, the methods and data provided earlier in Section 6.4.5 can be used.

6.6.3.2 Surface Area Constraint. The surface area constraint can be evaluated employing the same approach used to evaluate the thermal block constraint. Before beginning, Equation VI-86 should be evaluated to ensure that ΔT_{sa} exceeds $(\Delta T_y)_{min}$, since $(\Delta T_y)_{min}$ establishes the minimum excess isotherm that can be evaluated using these methods.

The distance offshore to the ΔT_{sa} isotherm (the isotherm associated with the legal surface area constraint) can be found as:

$$y_{sa} = 3D_p \left(\frac{\Delta T_c}{\Delta T_{sa}} \right)^2 \quad \text{for } y \geq 6D_p \qquad \text{(VI-91)}$$

where

y_{sa} = distance offshore at ΔT_{sa} isotherm (m)

The surface area enclosed by that ΔT_{sa} isotherm can be estimated as:

$$A_s = 6D_p \left(\frac{W_o + D_p}{2} \right) + \left(y_{sa} - 6D_p \right) \frac{W_o}{2} \left(1 + \frac{y_{sa}}{6D_p} \right) \qquad \text{(VI-92)}$$

where

$$W_o = \frac{2Q_p}{U_p \, d_s}$$

When the estuary depth drops off rapidly from the outfall location, an appropriate average depth would be the depth to the bottom of the discharge orifice. If $A_s < A_{sa}$, then the surface area constraint is not violated.

When y_{sa} exceeds the width of the estuary, Equation VI-92 should not be used to find A_s. Instead, a surface area based on steady state, well mixed conditions is more appropriate and can be found from the following expression:

$$A_s = W \left[\frac{1}{C_1} + \frac{1}{C_2} \right] \ln \left(\frac{\Delta T_{sa}}{\Delta T_{ss}} \right) \qquad \text{(VI-93)}$$

where

W = width of estuary (m)

$$C_1 = 1/2 \left[R/(A_t D_1) + \sqrt{(R/A_t D_1)^2 + (4WL/(\rho C_p A_t D \cdot 24 \cdot 3600))} \right]$$

$$C_2 = 1/2 \left[R/(A_t D_1) + \sqrt{(R/A_t D_1)^2 + (WK/(\rho C_p A_t D_1 \cdot 24 \cdot 3600))} \right]$$

and ΔT_{ss} was given by Equation VI-90.

When $A_s \le A_{sa}$, the surface area constraint is not exceeded.

6.6.3.3 Surface Temperature Constraint. This section provides a method for estimating the surface temperature of a buoyant plume resulting from a subsurface discharge. Slack tide conditions and a horizontal discharge configuration are considered. A horizontal configuration should approximate conditions under which the lowest maximum surface water temperature excess is attained.

When the ambient water density is constant over depth the following two dimensionless parameter groups are needed:

$$G = \frac{h}{D_p} \qquad \text{(VI-94)}$$

and

$$F \text{ (Froude Number)} = \frac{1.07\ U_p}{\sqrt{\frac{\rho - \rho_p}{\rho} D_p g}} \qquad \text{(VI-95)}$$

After calculating G and F, Figure VI-35 can be used to find S_o, the centerline dilution relative to the virtual source position. From this information, the maximum surface temperature elevation can be estimated as:

$$\Delta T_{surface} = \frac{\Delta T_c}{1.15 S_o} \qquad \text{(VI-96)}$$

If $\Delta T_{surface} < \Delta T_{st}$ (the legal allowable surface temperature excess), the surface temperature constraint is not violated.

In cases where the estuary is stratified more often than not at the power plant site, the maximum surface temperature calculation would more appropriately be performed under stratified conditions. If the stratification is substantial, it is possible the discharge may be prevented from reaching the surface entirely. A procedure is given here for a linearly stratified environment. Under stratified conditions the maximum height of rise of the thermal plume can be estimated by (Brooks, 1972):

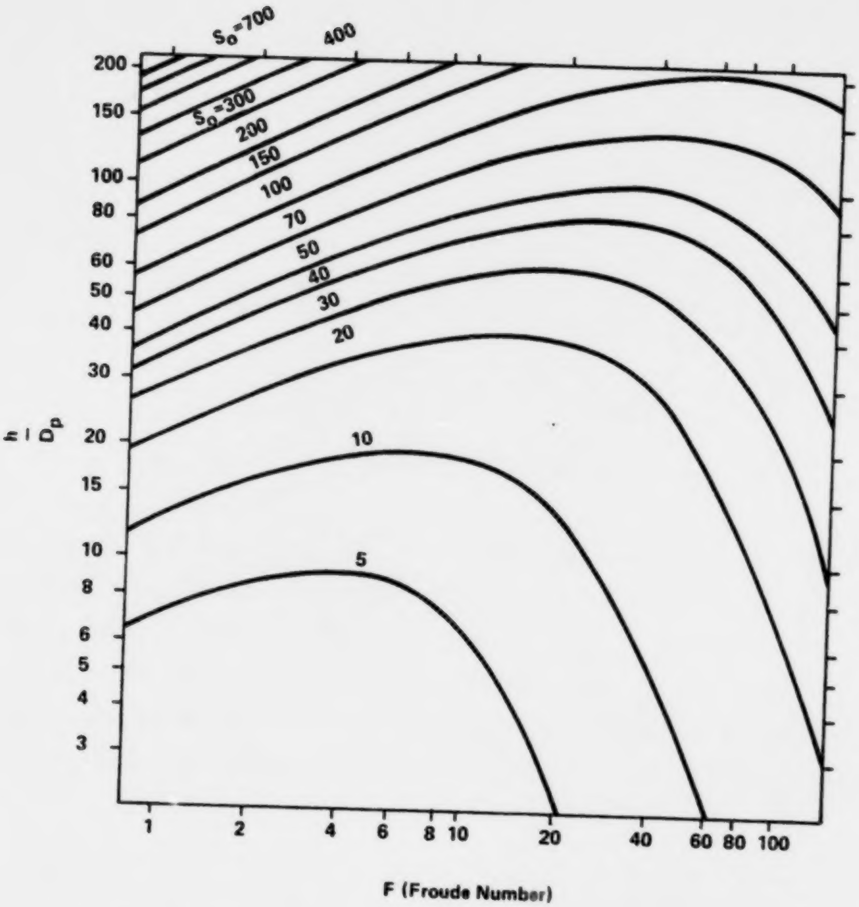

FIGURE VI-35 CENTERLINE DILUTION OF ROUND BUOYANT JET IN STAGNANT UNIFORM ENVIRONMENT (AFTER FAN AND BROOKS, 1969)

$$\frac{z_{max}}{D_p} = 3.86\ F^{1/4}\ T^{3/8} \qquad \text{(VI-97)}$$

where

$$F = \frac{1.07\ U_p}{\sqrt{\frac{\rho_s - \rho_p}{\rho_s} D_p g}}$$

$$T = \frac{0.87\ (\rho_s - \rho_p)}{D_p\ (\frac{-d\rho}{dz})}$$

z_{max} = maximum height of rise of thermal plume (m)

$\frac{d\rho}{dz}$ = linear density gradient ($kg/m^3/m$)

Using Equation VI-97, the maximum rise of the thermal plume can be estimated. If it is less than the depth of water, the plume remains submerged. If, however, z_{max} exceeds the water depth, the plume will surface. In this case the methods given previously for the nonstratified case can be used to estimate the maximum surface temperature where the ambient water density should be chosen to be the depth-averaged mean.

6.7 TURBIDITY

6.7.1 Introduction

Turbidity is a measure of the optical clarity of water and is dependent upon the light scattering and absorption characteristics of both suspended and dissolved material in the water column (Austin, 1974). The physical definition of turbidity is not yet fully agreed upon, and varies from equivalence with the scattering coefficient (Beyer, 1969), to the product of an extinction coefficient and measured pathlength (Hodkinson, 1968), and to the sum of scattering and absorption coefficients (VandeHulst, 1957). Turbidity affects water clarity and apparent water odor, and hence is of aesthetic significance. It also affects light penetration, so that increased turbidity results in a decreased photic zone depth and a decrease in primary productivity.

Turbidity levels in an estuary are likely to vary substantially in both temporal and spatial dimensions. Temporal variations occur as a function of seasonal river discharge, seasonal water temperature changes, instantaneous tidal current, and wind speed and direction. Spatially, turbidity varies as a function of water depth, distance from the head of the estuary, water column biomass content, and salinity level. Much of the complexity in the analysis of turbidity results from different sources of turbidity responding differently to the controlling variables mentioned above. As an example, increased river discharge tends to increase turbidity because of increased inorganic suspended sediment load. However, such an increase curtails light penetration, thus reducing water column photosynthesis. This, in turn, reduces the biologically induced turbidity.

Methods employed to monitor turbidity include use of a "turbidimeter". Light extinction measurements are commonly given in Jackson Turbidity Units (JTU) which are based on the turbidity of a standard clay suspension. Once standardized, this arbitrary scale* can be used as a basis to measure changes in turbidity.

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*The JTU scale is an arbitrary scale since it cannot be directly related to physical units when used as a calibration basis for turbidimeter measurement.

The turbidity calibration scale is given in APHA (1980). From a measured change in turbidity a relative change in water quality may be inferred. Estuarine water is almost always extremely turbid, especially when compared to ocean or lake waters.

The JTU scale is not the only available turbidity scale. In 1926 Kingsbury and Clark devised a scale based on a Formazin suspension medium which resulted in Formazin Turbidity Units (FTU's). More recently volume scattering functions (VSF) and volume attenuation coefficients have been proposed (Austin, 1974). However, JTU's are still most commonly used as an indicator of estuarine turbidity levels.

As a rough indication of the wide variations possible in turbidity, Figure VI-36 shows suspended solid concentrations for the various sub-bays of San Francisco Bay for one year (Pearson, et al, 1967). The solid line shows annual mean concentrations while the dashed lines indicate concentrations exceeded by 20% and 80% of the samples taken at each station over the one year time period. These variations at stations located near bay heads (left and right extremities of Figure VI-36) typically exceed 300% of the annual 20th percentile values. Use of extreme high/low values would produce correspondingly larger annual variations.

6.7.2 Procedure to Assess Impacts of Wastewater Discharges on Turbidity or Related Parameters

Numerous states have enacted water quality standards which limit the allowable turbidity increase due to a wastewater discharge in an estuary or coastal water body. The standards, however, are not always written in terms of turbidity, but are sometimes expressed as surrogate parameters such as light transmittance or Secchi disk. The following three standards provide illustrations:

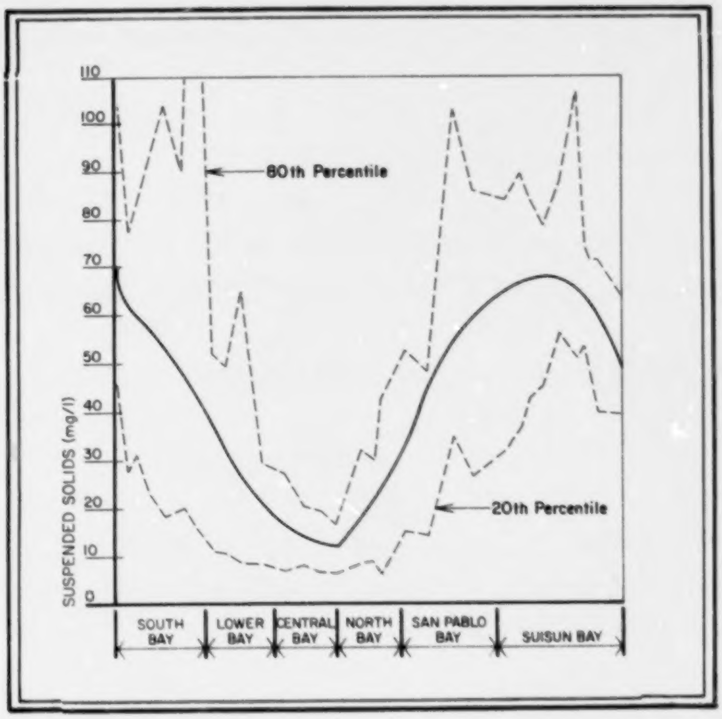

FIGURE VI-36 MEAN SUSPENDED SOLIDS IN SAN FRANCISCO BAY
FROM: PEARSON ET AL., 1967, PG V-15

For class AA water in Puget Sound, State of Washington:

> Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

For class A water in the State of Hawaii:

> Secchi disk or Secchi disk equivalent as "extinction coefficient" determinations shall not be altered more than 10 percent.

For coastal waters off the State of California:

> The transmittance of natural light shall not be significantly reduced at any point outside of the initial dilution zone. A significant difference is defined as a statistically significant difference in the means of two distributions of sampling results at the 95 percent confidence level.

These standards illustrate the need for developing interelationships between turbidity related parameters, since data might be available for one parameter while the state standard is expressed in terms of another. Based on these considerations methods will be presented to:

- predict the turbidity in the receiving water at the completion of initial dilution
- predict the suspended solids concentrations in the receiving water at the completion of initial dilution
- relate turbidity and light transmittance data, and
- relate Secchi disk and turbidity data.

By treating turbidity as a conservative parameter the turbidity in the receiving water at the completion of initial dilution can be predicted as:

$$T_f = T_a + \frac{T_e - T_a}{S_a} \qquad \text{(VI-98)}$$

where

T_f = turbidity in receiving water at the completion of initial dilution (typical units: JTU)

T_a = ambient or background turbidity

T_e = effluent turbidity

S_a = initial dilution

Initial dilution can be predicted based on the methods presented earlier in Section 6.5.2. Equation VI-98 can be used, then, to directly evaluate those standards written in terms of maximum allowable turbidity or turbidity increase.

An expression similar to Equation VI-98 can be used to evaluate the suspended solids concentration in an estuary following completion of initial dilution. Specifically

$$SS_f = SS_a + \frac{SS_e - SS_a}{S_a} \qquad \text{(VI-99)}$$

where

SS_f = suspended solids concentration at completion of initial dilution, mg/l

SS_a = ambient suspended solids concentration, mg/l

SS_e = effluent suspended solids concentration, mg/l

S_a = initial dilution

Consider now a situation where light transmittance data have been collected but the state standard is expressed in terms of turbidity. A relationship between the two parameters would be useful. Such a relationship can be developed by first considering the Beer-Lambert law for light attenuation:

$$T_d = \exp(-\alpha d) \tag{VI-100}$$

where

T_d = fraction of light transmitted over a depth d, dimensionless

α = light attenuation, or extinction coefficient, per meter

d = vertical distance between two locations where light is measured, meters

Austin (1974) has shown that the attenuation coefficient is expressible in terms of turbidity as:

$$\alpha = k \cdot JTU \tag{VI-101}$$

where

JTU = turbidity, in Jackson turbidity units

k = coefficient ranging from 0.5 to 1.0

Combining Equations VI-100 and VI-101 the turbidity is expressible as:

$$JTU = -\frac{1}{kd} \ln T_d \tag{VI-102}$$

The increased turbidity (JTU) is expressible as:

$$\Delta JTU = \frac{-1}{kd} \ln \left(\frac{T_{d_2}}{T_{d_1}} \right) \quad \text{(VI-103)}$$

where

T_{d_2} = light transmittance at the final turbidity

T_{d_1} = light transmittance at the initial turbidity

EXAMPLE VI-17

Vertical profiles of several water quality parameters, including percent light transmittance, have been collected in the vicinity of a municipal wastewater discharge in Puget Sound. Figure VI-37 shows each of the three profiles. If the maximum allowable turbidity increase is 5 NTU, does the discharge, based on the light transmittance profile shown in Figure VI-37, violate this requirement?

It is known that the wastefield is submerged between about 10 to 20 m below the water's surface. Light transmittances at these depths are about 18 to 20 percent. Deeper within the water column light transmittances are at background values of about 55 percent. Note that in the top few meters the light transmittances are between 0 and 10 percent. These low transmittances are not due to the wastefield, but rather are caused by a lens of turbid freshwater. Consequently, the following data will be used here:

- k = 0.5
- d = 1 m (i.e. percent transmittance measured over 1 m)
- T_{d_2} = 18 percent
- T_{d_1} = 55 percent

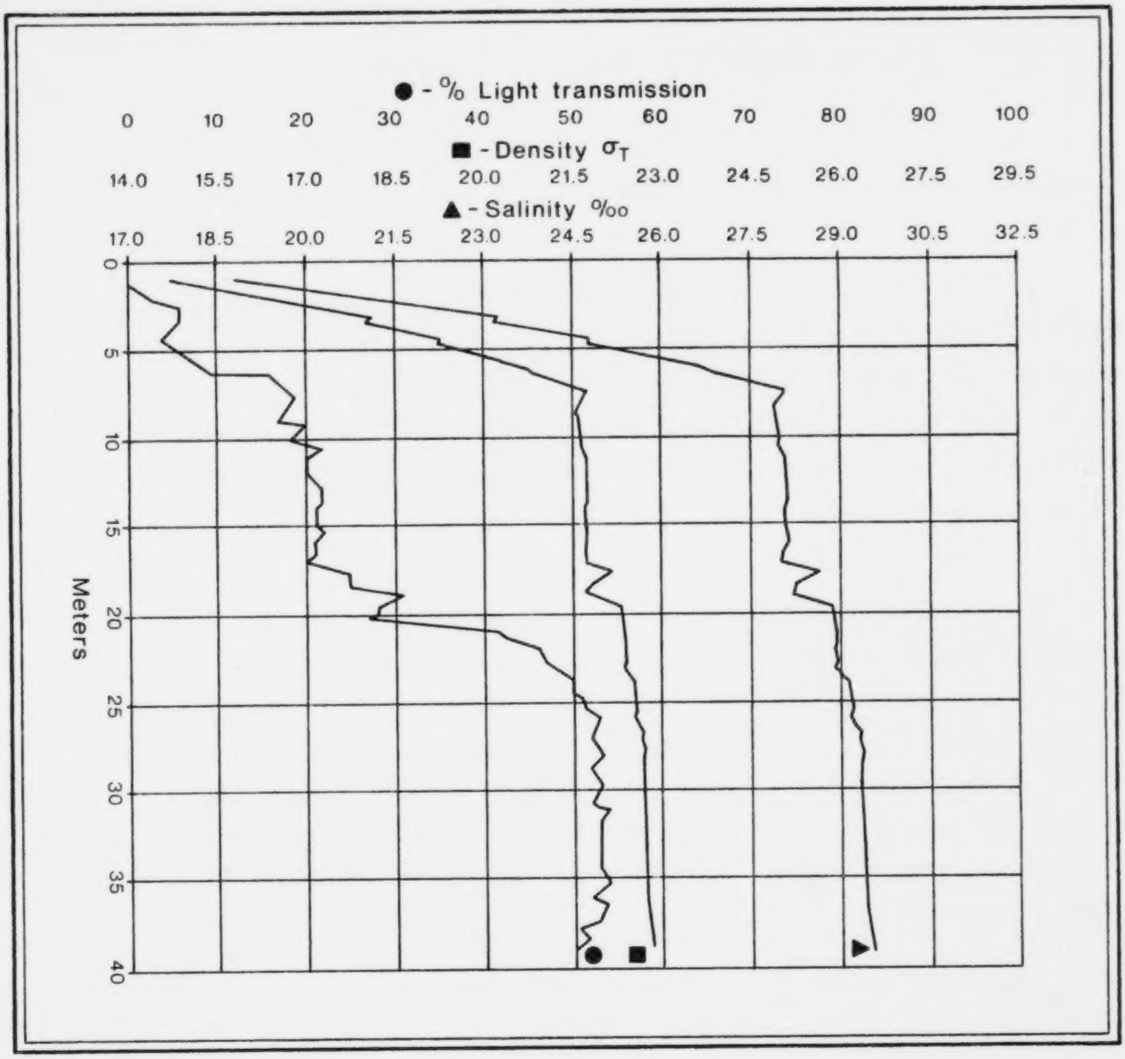

FIGURE VI-37 WATER QUALITY PROFILE OF SELECTED PARAMETERS NEAR A MUNICIPAL OUTFALL IN PUGET SOUND, WASHINGTON

The turbidity increase is:

$$\Delta JTU = \frac{-1}{(0.5)\ (1)} \ \ln \left(\frac{0.18}{0.55}\right) = 2.2 \text{ JTU}$$

Assuming JTU and NTU units are equivalent (EPA, 1979), then the increased turbidity is less than the 5.0 NTU allowable.

It is of interest to calculate the percent light transmittance within the plume that would cause a 5 NTU increase in turbidity. Using a typical background light transmittance of 50 percent found in central Puget Sound, the minimum light transmittance (T_{d_2}) is computed to be:

$$T_{d2} = \begin{cases} 4 \text{ percent for } k = 0.5 \\ 0.5 \text{ percent for } k = 1.0 \end{cases}$$

Light transmittances as low as 0.5 to 4 percent have been found due to causes other than the plume (e.g. plankton blooms and fresh water runoff), but the lowest light transmittances associated with the plume have been about 18 percent per meter.

END OF EXAMPLE VI-17

Secchi disk and turbidity can be related to each other in the following manner. Assume that the extinction coefficient of visible light (α) is directly proportional to turbidity (T) and inversely proportional to Secchi disk (SD), or:

$$\alpha = k_1 T \qquad \text{(VI-104)}$$

and

$$\alpha = \frac{k_2}{SD} \qquad \text{(VI-105)}$$

where k_1 and k_2 are constants which have not yet been specified. These two relationships have theoretical bases, as discussed in Austin (1974) and Graham (1968). Combining those two expressions, the relationship between

Secchi disk and turbidity becomes:

$$T = \frac{k_2}{k_1} \frac{1}{SD} \qquad \text{(VI-106)}$$

Typical values of k_1 and k_2 are:

k_1 = 0.5 to 1.0, where T is expressed in JTU's

k_2 = 1.7 where Secchi disk is expressed in meters

Thus Equation VI-106 provides a method of correlating turbidity and Secchi disk data.

When state standards are written in terms of Secchi disk, it is convenient to combine Equations VI-98 and VI-106 to yield:

$$\frac{1}{SD_f} = \frac{1}{SD_a} + \frac{\frac{1}{SD_e} - \frac{1}{SD_a}}{S_a} \qquad \text{(VI-107)}$$

or

$$SD_e = \left[\left(\frac{1}{SD_f} - \frac{1}{SD_a}\right)S_a + \frac{1}{SD_a}\right]^{-1} \qquad \text{(VI-108)}$$

where

SD_f = minimum allowable Secchi disk reading in receiving water such that the water quality standard is not violated

SD_a = ambient Secchi disk reading

Sa = minimum initial dilution which occurs when the plume surfaces

SD_e = Secchi disk of effluent

Since Secchi disk measurements are made from the water's surface downward, critical conditions (in terms of the Secchi disk standard) will occur when the initial dilution is just sufficient to allow the plume to surface. It is notable that maximum turbidity or light transmittance impacts of a wastewater plume will occur when the water column is stratified, the plume remains submerged, and initial dilution is a minimum. Under these same conditions, however, Secchi disk readings might not be altered at all, if the plume is trapped below the water's surface at a depth exceeding the ambient Secchi disk depth.

EXAMPLE VI-18

A municipality discharges its wastewater through an outfall and diffuser system into an embayment. The state standard specifies that the minimum allowable Secchi disk is 3m. Determine whether the discharge is likely to violate the standard. Use these data:

SD_a = 5 to 10m, observed range

S_a = 75, minimum initial dilution when the plume surfaces

One method of approaching the problem is to assume that violation of the water quality standard is incipient (i.e. SD_f = 3m). Under these conditions the effluent Secchi disk would have to be:

$$SD_e = \left[\left(\frac{1}{3} - \frac{1}{5}\right) 75 + \frac{1}{5}\right]^{-1} = 0.1 \text{ m}$$

$$= 4 \text{ inches}$$

Thus, if the Secchi disk of the effluent exceeds 4 inches, the standards will not be violated even under these critical conditions. It would be a simple matter to measure the Secchi disk of the treated effluent to see whether the standard could be violated or not.

END OF EXAMPLE VI-18

6.8 SEDIMENTATION

6.8.1 Introduction

Like turbidity, sedimentation is a multifaceted phenomenon in estuaries. As in rivers, estuaries transport bed load and suspended sediment. However with the time varying currents in estuaries, no equilibrium or steady state conditions can be achieved (Ippen, 1966). Additionally, while any given reach of a river has reasonably constant water quality conditions, an estuary can vary from fresh water (1 ppt. salinity) to sea water (30 ppt. salinity), and from a normally slightly acidic conditon near the head to a slightly basic condition at the mouth. The behavior of many dissolved and suspended sediments varies substantially across these pH and salinity gradients. Many colloidal particles* agglomerate and settle to the bottom. In general, all estuaries undergo active sedimentation which tends to fill them in. It is also true for essentially all U.S. estuaries that the rate of accumulation of sediment is limited not by the available sources of sediment but by the estuary's ability to scour unconsolidated sediments from the channel floor and banks.

6.8.2 Qualitative Description of Sedimentation

Before presenting what quantitative information is available concerning sediment distribution in an estuary, a qualitative description of sediment sources, types and distribution will be helpful. Sediment sources may be divided into two general classes: sources external to the estuary and sources internal to the estuary (Schultz and Simmons, 1957). The major sources of sediment within each category are shown below. By far the largest external contributor is the upstream watershed.

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*Colloidal particles are particles small enough to remain suspended by the random thermal motion of the water.

1. External:
    - Upstream watershed
    - Banks and stream bed of tributaries
    - Ocean areas adjacent to the mouth of the estuary
    - Surface runoff from land adjacent to the estuary
    - Wind borne sediments
    - Point sources (municipal and industrial)

2. Internal:
    - Estuarine marsh areas
    - Wave and current resuspension of unconsolidated bed materials
    - Estuarine biological activity
    - Dredging

General characterizations of U.S. estuarine sediments have been made by Ippen (1966) and by Schultz and Simmons (1957). Many individual case study reports are available for sediment characterization of most of the larger U.S. estuaries (i.e. Columbia River, San Francisco Bay, Charles Harbor, Galveston Bay, Savannah Harbor, New York Harbor, Delaware River and Bay, etc.). In general, estuarine sediments range from fine granular sand (0.01 in. to 0.002 in. in diameter) through silts and clays to fine colloidal clay (0.003 in. or less in diameter) (Ippen, 1966). Very little, if any, larger material (coarse sand, gravel, etc.) is found in estuarine sediments. Sand plays a relatively minor role in East Coast, Gulf Coast and Southern Pacific Coast estuaries. Usually it constitutes less than 5% by volume (25% by weight) of total sediments for these estuaries with most of this sand concentrated near the estuarine mouth (Schultz & Simmons, 1957). By contrast, sand is a major element in estuarine shoaling for the north Pacific estuaries (i.e. Washington and Oregon coasts). These estuaries are characterized by extensive oceanic sand intrusion into the lower estuarine segments and by extensive bar formations near the estuarine mouth. The relative distribution of silts and clays, of organic and inorganic material within different estuaries, and, in fact, the distribution of shoaling and scour areas within estuaries, varies widely.

6.8.3 Estuarine Sediment Forces and Movement

As sediments enter the lower reaches of a river and come under tidal influence they are subjected to a wide variety of forces which control their movement and deposition. First, net velocities in the upper reaches of estuaries are normally lower than river velocities. Additionally, the water column comes under the influence of tidal action and thus is subject to periods of slack water. During these periods coarse sand and larger materials settle. The scour velocity required to resuspend a particle is higher than that required to carry it in suspension. Thus, once the coarser particles settle out in the lower river and upper estuarine areas, they tend not to be resuspended and carried farther into the estuary (U.S. Engineering District, San Francisco, 1975). Exceptions to this principle can come during periods of extremely high river discharge when water velocities can hold many of these particles in suspension well into or even through an estuary. Table VI-26 lists approximate maximum allowable velocities to avoid scour for various sizes of exposed particles. Values are approximate and are for unarmored sediment (sediment not protected by a covering of larger material).

Sediments are subject to gravitational forces and have size-dependent settling velocities. In highly turbulent water the particle fall velocities can be small compared to background fluid motion. Thus gravitational settling occurs chiefly in the relatively quiescent, shallow areas of estuaries or during periods of slack water. As mentioned earlier, particle settling attains a maximum in each tidal cycle during high water slack and low water slack tides. During periods of peak tidal velocity (approximately half way between high and low water) resuspension of unconsolidated sediment may occur. Thus during a tidal cycle large volumes of sediment are resuspended, carried upstream with flood flow, deposited, resuspended, and carried downstream on the ebb tide. Only those particles deposited in relatively quiescent areas have the potential for long term residence. Compounding this cyclic movement of sediments are seasonal river discharge variations which alter estuarine hydrodynamics. Thus, sediment masses tend to shift from one part of an estuary to another (Schultz and Simmons, 1975).

TABLE VI-26

MAXIMUM ALLOWABLE CHANNEL VELOCITY TO AVOID BED SCOUR (FPS) (KING, 1954)

Original material excavated	Clear water, no detritus	Water transporting colloidal silts	Water transporting non-colloidal silts, sands, gravels or rock fragments
Fine sand	1.50	2.50	1.50
Sandy loam.	1.75	2.50	2.00
Silt loam	2.00	3.00	2.00
Alluvial silts.	2.00	3.50	2.00
Ordinary firm loam.	2.50	3.50	2.25
Volcanic ash.	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay.	3.75	5.00	3.00
Graded, loam to cobbles	3.75	5.00	5.00
Alluvial silt	3.75	5.00	3.00
Graded, silt to cobbles	4.00	5.50	5.00
Coarse gravel	4.00	6.00	6.50
Cobbles and shingles.	5.00	5.50	6.50
Shales and hardpans	6.00	6.00	5.00

As fresh waters encounter areas of significant salinity gradients extremely fine particles (primarily colloidal clay minerals) often destabilize (coagulate) and agglomerate to form larger particles (flocculate). The resulting floc (larger agglomerated masses) then settles to the bottom. Coagulation occurs when electrolytes, such as magnesium sulfate and sodium chloride, "neutralize" the repulsive forces between clay particles. This allows the particles to adhere upon collision (flocculation), thus producing larger masses of material. Flocculation rates are dependent on the size distribution and relative composition of the clays and electrolytes and upon local boundary shear forces (Ippen, 1966, and Schultz and Simmons, 1957). Flocculation occurs primarily in the upper central segments of an estuary in the areas of rapid salinity increase.

Movement of sediments along the bottom of an estuary does not continue in a net downstream direction as it does in the upper layers and in stream reaches. In all but a very few extremely well mixed estuaries upstream bottom currents predominate at the mouth of an estuary. Thus, upstream flow is greater than downstream flow at the bottom. This is counterbalanced by increased surface downstream flow. However, net upstream flow along the bottom results in a net upstream transport of sediment along the bottom of an estuary near the mouth. Thus, sediments and flocs settling into the bottom layers of an estuary near the mouth are often carried back into the estuary rather than being carried out into the open sea. Consequently, estuaries tend to trap, or to conserve sediments while allowing fresh water flows to continue on out to sea. At some point along the bottom, the upstream transport is counter-balanced by the downstream transport from the fresh water inflow. At this point, termed the "null zone", there is essentially no net bottom transport. Here sediment deposition is extensive. In a stratified estuary this point is at the head of the saline intrusion wedge. In a partially mixed estuary it is harder to pinpoint. Nonetheless, sedimentation is a useful parameter to analyze and will be handles in a quantitative manner beginning with Section 6.8.4.

To this point, flow in a fairly regular channel has been assumed. However, in many estuaries geomorphic irregularities exist. Such irregularities (e.g. narrow headlands) create eddy currents on their lee sides. These eddy currents, or gyres, slow the sediment movement and allow local shoaling. Additionally, large shallow subtidal or tidal flatlands exist in many estuaries. Such areas are usually well out of the influence of primary currents. As a result local water velocities are usually low and increased shoaling is possible.

Wind and waves also have a major influence on estuarine sediment distribution. Seasonal wind driven currents can significantly alter water circulation patterns and associated velocities. This in turn determines, to a large extent, the areas of net shoaling and scour throughout an estuary. Local wind driven and oceanic waves can create significant scour forces. Such scour, or particle resuspension, is particularly evident in shallow areas where significant wave energy is present at the sediment/water interface. Local wind driven waves are a major counterbalancing force to low velocity deposition in many shallow estuarine areas (U.S. Engineering District, San Francisco, 1975).

Finally, oceanic littoral currents (long shore currents) interact with flood and ebb flows in the area of an estuary mouth. Particularly in the Pacific Northwest, sandy sediment fed from such littoral drift is a major source of estuarine sediment, and the interference of littoral drift with normal flood and ebb flows is the major factor creating estuarine bars.

Figure VI-38 shows the schematic flow of annual sediment movement through San Francisco Bay. With the exception of the magnitude of annual dredging, this is typical for most U.S. estuaries. The most important thing to observe is the dominance of resuspension and redeposition over all other elements of sediment movement including net inflow and outflow. Also note that there is a net annual accumulation of deposited sediment in the bay. This figure is also helpful in conceptualizing the sediment trap or sediment concentration characteristic of estuaries. In any year, 8-10 million cubic yards flow into the estuary and 5 to 9 million cubic yards flow out. However, over 180 million cubic yards are actively involved in annual sediment transport within the estuary.

Figure VI-39 is an idealized conceptualization of the various sediment-related processes in an estuary. It must be remembered that these processes actually overlap spatially much more than is shown and that the processes active at any given location vary considerably over time.

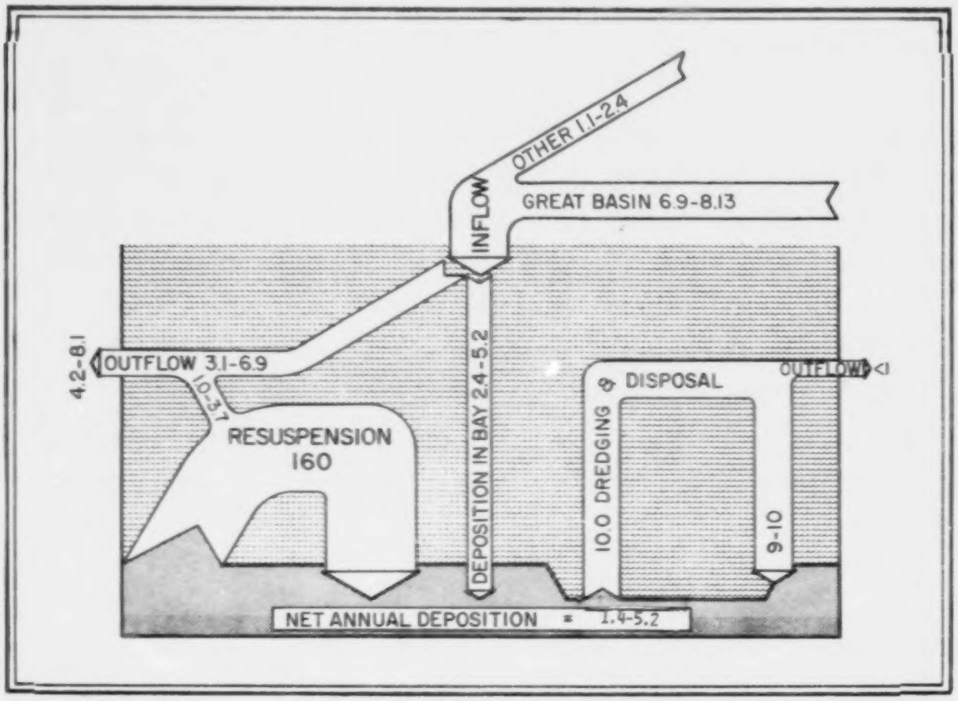

FIGURE VI-38 SEDIMENT MOVEMENT IN SAN FRANCISCO BAY SYSTEM (MILLION CUBIC YARDS), FROM: U.S. ENGINEERING DISTRICT, SAN FRANCISCO, 1975)

From this qualitative analysis, there are some general statements which can be made. Ippen (1966) drew the following conclusions on the distribution of estuarine sediments:

a) The major portion of sediments introduced into suspension in an estuary from any source (including resuspension) during normal conditions is retained therein, and if transportable by the existing currents is deposited near the ends of the salinity intrusion, or at locations of zero net bottom velocity.

b) Any measure contributing to a shift of the regime towards stratification causes increased shoaling. Such measures may be: structures to reduce the tidal flow and prism, diversion of additional fresh water into the estuary, deepening and

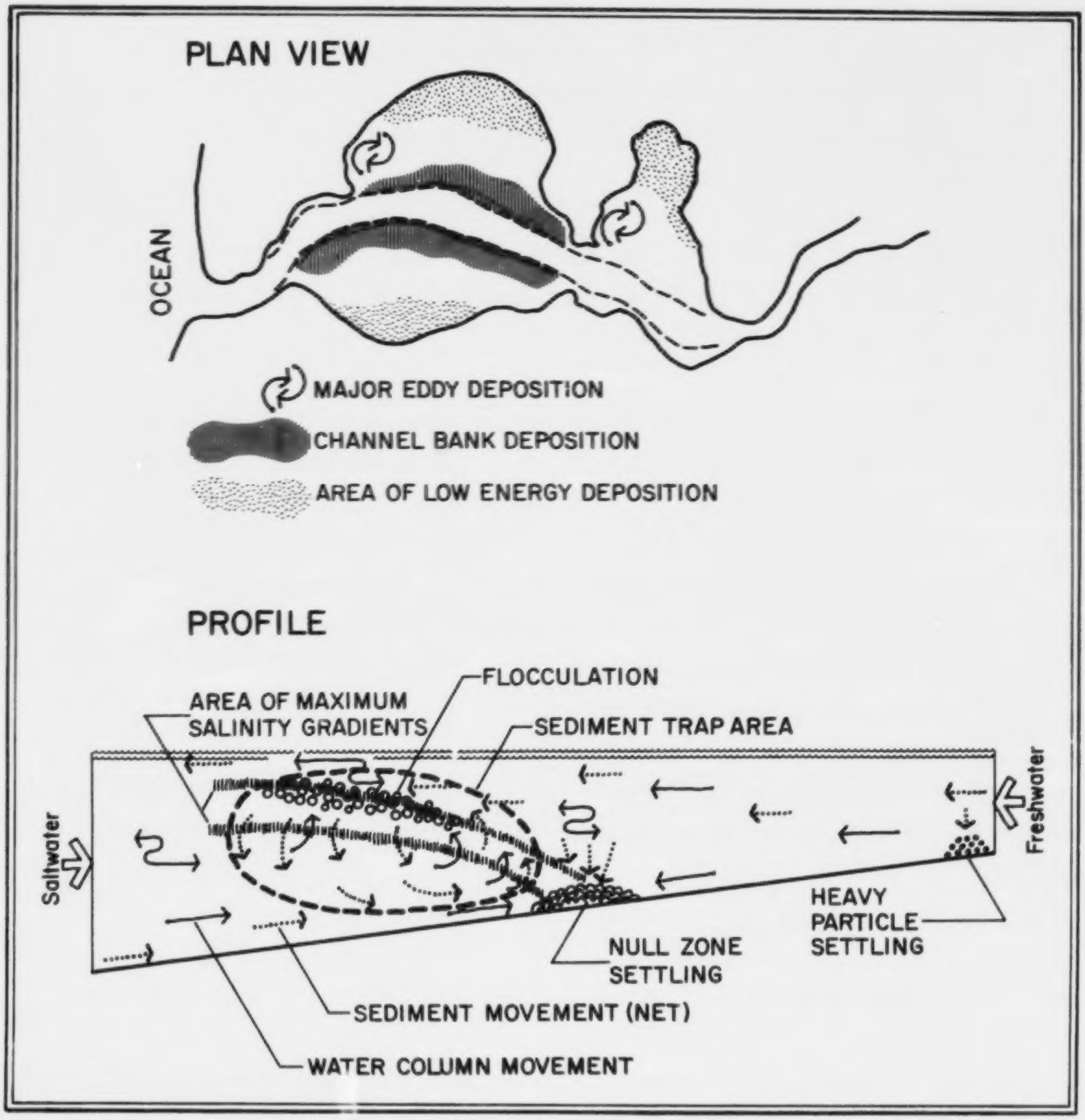

FIGURE VI-39 IDEALIZED ESTUARINE SEDIMENTATION

narrowing of the channel.

c) Sediments settling to the bottom of an estuary are generally transported upstream and not downstream. Such sediments may at some upstream point be resuspended into the upper layers and carried back downstream.

d) Sediments accumulate near the ends of the intrusion zone and form shoals. Shoals also form where the net bottom velocity is zero (in the null zone).

e) The intensity of shoaling is most extreme near the end of the intrusion for stratified estuaries and is lessened in the well mixed estuary.

f) Shoals occur along the banks of the main estuarine channel where water is deep enough to prevent wave induced scour and where velocities are reduced from main channel velocities sufficiently to allow settling.

Schultz and Simmons (1957) made similar conclusions but added the presence of shoaling at the mouth where flood and ebb currents intercept littoral drift.

6.8.4 Settling Velocities

As was stated in the previous section, settling velocities do not play a great role in controlling sedimentation patterns in estuaries as they do in lakes. However, it is informative to assess settling rates for various size particles. The possible size classifications of particles and their general inclusive diameter sizes are shown in Table VI-27 Table VI-28 lists terminal settling velocities for each particle size assuming spherical particles and density of 2.0* in quiescent water. From this table it can be

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*The density of many inorganic suspended particles is approximately equal to that of sand (2.7 gm/cm^3) while that of biomass and organic detritus is usually much closer to that of water and can be assumed to be about 1.1 gm/cm^3.

TABLE VI-27

SEDIMENT PARTICLE SIZE RANGES (AFTER HOUGH, 1957)

	PARTICLE SIZE RANGE			
	Inches		Millimeters	
	$D_{max.}$	$D_{min.}$	$D_{max.}$	$D_{min.}$
Derrick STONE	120	36	--	--
One-man STONE	12	4	--	--
Clean, fine to coarse GRAVEL	3	1/4	80	10
Fine, uniform GRAVEL	3/8	1/16	8	1.5
Very coarse, clean uniform SAND	1/8	1/32	3	0.8
Uniform, coarse SAND	1/8	1/64	2	0.5
Uniform, medium SAND	--	--	0.5	0.25
Clean, well-graded SAND AND GRAVEL	--	--	10	0.05
Uniform, fine SAND	--	--	0.25	0.05
Well-graded, silty SAND AND GRAVEL	--	--	5	0.01
Silty SAND	--	--	2	0.005
Uniform SILT	--	--	0.05	0.005
Sandy CLAY	--	--	1.0	0.001
Silty CLAY	--	--	0.05	0.001
CLAY (30 to 50% clay sizes)	--	--	0.05	0.0005
Collodal CLAY (-2μ>50%)	--	--	0.01	10^{-6}

(After B. K. Hough, Basic Soils Engineering, p. 69, Values listed are approximate)

TABLE VI-28

RATE OF FALL IN WATER OF SPHERES OF VARYING RADII AND CONSTANT DENSITY OF 2[a] AS CALCULATED BY STOKES' LAW[b,c] (MYSELS,1959)

Radius	Terminal velocity	
mm.	cm./sec.	cm./min.
10	(>1)	
1	(>1)	
0.1	(>1)	
0.01	2.2×10^{-2}	1.3
10^{-3}	2.2×10^{-4}	0.013
10^{-4}	2.2×10^{-6}	1.3×10^{-4}
10^{-5}	2.2×10^{-8}	1.3×10^{-6}
10^{-6}	2.2×10^{-10}	1.3×10^{-8}
10^{-7}	(2.2×10^{-12})	

[a] To apply to other conditions, multiply the u value by the pertinent density difference and divide it by the pertinent viscosity in centipoises.

[b] Values in parentheses are calculated by Stokes' law under conditions where this law is not applicable.

[c] Stokes law states that the terminal velocity is proportional to the particle radius squared, the difference in density and inversely proportional to the liquid viscosity.

inferred that particles of the medium sand class and coarser probably settle to the bottom within a very short time after entering an estuary.

Turning to the other end of the particle size scale of Table VI-28, particles with a diameter of 10^{-6}mm fall only 3.1 x 10^{-7} inches per hour in the most favorable environment (calm waters). Such a settling rate is not significant in the estuarine environment. Figure VI-40 shows the quiescent settling rates for particle sizes in between these two extremes since this intermediate size group is of real significance in estuarine management (primarily silts). For particles smaller than those shown in Figure VI-40, gravitational settling is not a significant factor in controlling particle motion. Particles substantially larger than the range shown in Figure VI-40 tend to settle above, or at, the head of an estuary.

Combining Figure VI-40 (fall per tidal cycle)** with known segment flushing times (in tidal cycles) the size of particles tending to settle out in each segment can be estimated. If such predictions reasonably match actual mean segment sediment particle size, then this method can be useful in predicting changes in sediment pattern. Anticipated changes in river-borne suspended sediment load by particle size can be compared to areas where each size of particle would tend to settle. This would then identify areas which would either be subject to increased shoaling or reduced shoaling and increased scour. This type of analysis has been more successful when applied to organic detritus material than for inorganic suspended loads.

A number of simplifying assumptions have gone into this settling velocity analysis. The most significant of these are:

1. Water column density changes have been ignored. Inclusion of this factor would slightly reduce the settling velocity with increased depth. This effect will be more significant for organic matter because of its lower density.

2. Dispersive phenomena and advective velocities have not been considered.

**Based on a 12.4 hour tidal cycle.

3. Table VI-27 and Figure VI-40 are based on the fall of perfectly spherical particles. Non-spherical particles have lower settling velocities.

4. Interference between particles has not been considered. However, in a turbulent, sediment-laden estuary such interference is possible (hindered settling). The analysis of the effect of interference on settling velocities was covered in Chapter V for lakes. This analysis is also basically valid for estuaries. The effects introduced there can be applied to Figure VI-40 velocities to adjust for particle interference.

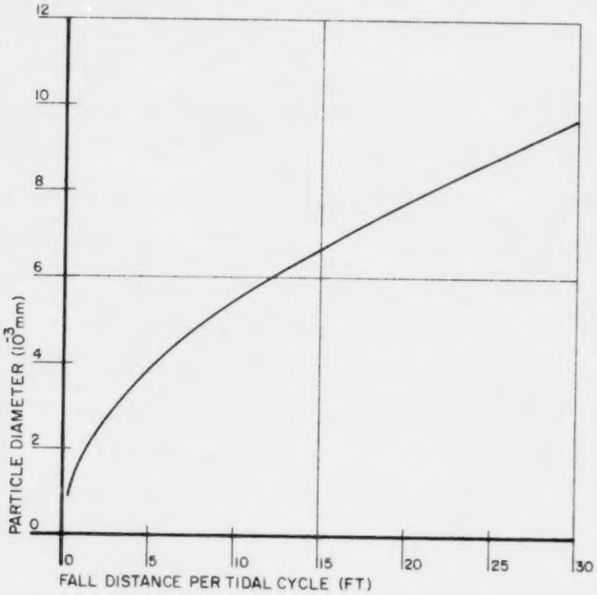


FIGURE VI-40 PARTICLE DIAMETER VS SETTLING FALL PER TIDAL CYCLE (12.3 HRS) UNDER QUIESCENT CONDITIONS (SPHERES WITH DENSITY 2.0 GM/CM^3)

6.8.5 Null Zone Calculations

It was previously mentioned that substantial shoaling occurs in the area of the null zone. It is possible to estimate the location of this zone, and hence the associated shoaling areas, as a function of water depth and river discharge. In addition to the importance of the null zone to shoaling, Petersone and Conomos (Peterson, et al., 1975) established the biological and ecological importance of this area in terms of planktonic production. The null zone, therefore, is both an area of potential navigational hazard and an area of major ecological importance to the planner.

Silvester (1974) summarized the analysis for estimating the location of the null zone with respect to the mouth of an estuary. The basic equation used in this analysis is:

$$\frac{\bar{S}_n}{S_o} = \frac{1000}{0.7 S_o F_n^2} \frac{U_r^2}{gd} \qquad \text{(VI-109)}$$

where

$\bar{S}_n$ = mean salinity (averaged vertically and over a tidal cycle) at the null point (n), (ppt)

S_o = ocean surface salinity adjacent to the estuary in parts per thousand (ppt),

U_r = fresh water flow velocity, (ft/sec)

g = gravational acceleration = 32.2 ft/sec^2,

d = estuarine depth, (ft)

F_n = densimetric Froude number at the null zone where F_n is defined by:

$$F_n = U_r / \sqrt{(\Delta\rho/\rho_n) gd} \qquad \text{(VI-110)}$$

where

$\Delta\rho/\rho_n$ = difference between fresh water density and that at the null zone (averaged over the depth of the water column) divided by the density at the null zone. This value may be approximated for estuarine waters by:

Combining Equations VI-109 and VI-110 and solving for $\frac{\Delta\rho}{\rho_n}$ yields

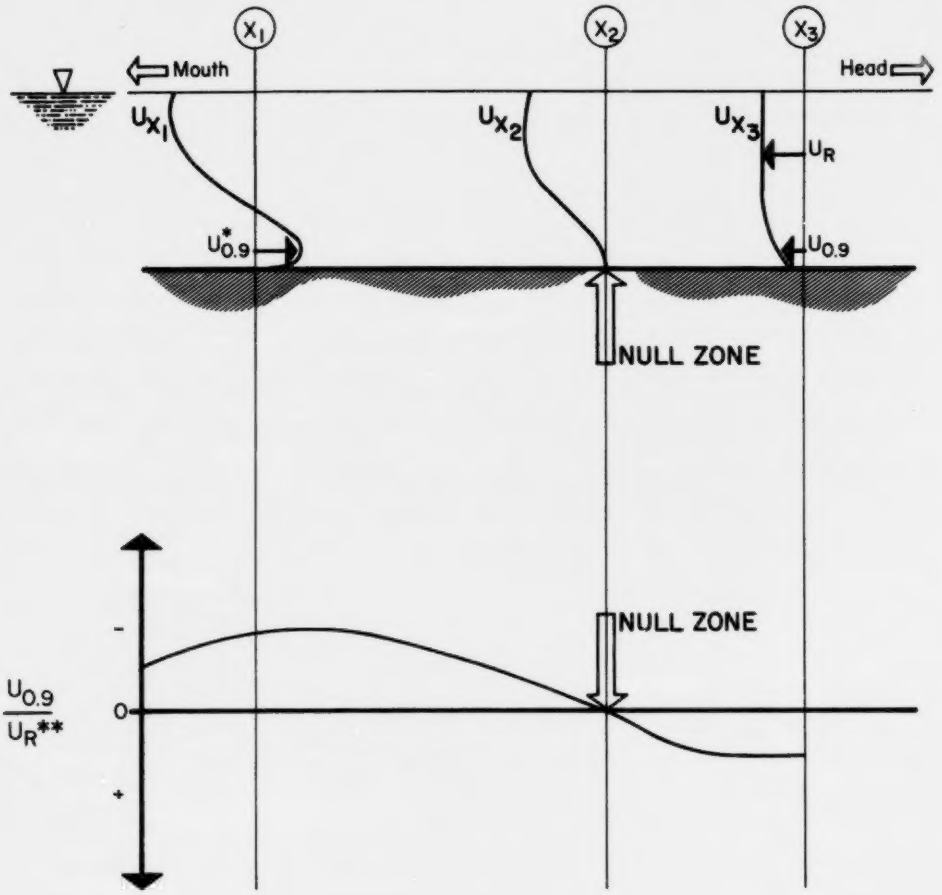
$$\frac{\Delta\rho}{\rho_n} = \frac{0.7}{1000} \bar{S}_n \qquad \text{(VI-111)}$$

This formulation is particularly good for channels which are either maintained at a given depth (dredged for navigation) or are naturally regular, as "d" represents mean cross section channel depth at the null zone.

The use of these equations first requires location of the present null zone. This can most easily be done by measuring and averaging bottom currents over one tidal cycle to locate the point where upstream bottom currents and downstream river velocities are exactly equal, resulting in no net flow. This situation is schematically shown in Figure VI-41.

When this point has been established for one set of river discharge conditions, Equation VI-111 can be substituted into Equation VI-110 to calculate F_n. This F_n value is an inherent characteristic of an estuary and can be considered to be constant regardless of the variations in flow conditions or null zone location (Silvester, 1974).

With this information and a salinity profile for the estuary (S_x plotted against x from x = 0 at the mouth of the estuary to x = L at the head) the location of future null zones may be calculated. Given the new conditions of U_r (changes in river discharge) or of d (changes in channel depth, as by dredging activity), Equation VI-109 will allow calculation of a new $\bar{S}_n$. This may be plotted on the salinity profile to caculate the location of a new null zone position. Even though these changes will produce a new estuarine salinity profile, the use of Equation VI-109 and the old (known) salinity profile will produce reasonably good estimates of longitudinal shifts in the location of the null zone. Salinity profiles for



* $U_{0.9}$ = tidally averaged velocity at a depth equal to 0.9 of the water column depth.

** U_R = river flow velocity

FIGURE VI-41 ESTUARINE NULL ZONE IDENTIFICATION

appropriate seasonal conditions should be used for each calculation (e.g. low flow profiles for a new low flow null zone calculation).

EXAMPLE VI-19

Estimation of Null Zone Location

An estuary has the tidally averaged salinity profile shown in the Salinity Table below. Mean channel depth in the area of the existing null zone is 18 feet and the salinity at that point is 10 parts per thousand (ppt). Current (low flow) river discharge velocity is 0.5 ft/sec. Normal winter (high flow) velocity is 1.8 ft/sec. It is desired to know where the null zone will be located in summer and winter if a 30 ft deep channel is dredged up to 70,000 feet from the mouth.

SALINITY DATA FOR EXAMPLE VI-19

Distance from mouth (1000ft)	5	15	25	35	45	55	65	75	85
Salinity. (ppt)	30	28	25	20	13	8	6	4	1

From equation VI-43 and equation VI-44

$$F_n = U_r \Big/ \sqrt{(.7/1000)\ (\bar{S}_n)\ (g)\ (d)}$$

$$= 0.5\ \text{ft/sec} \Big/ \sqrt{(7\times10^{-4})\ (10\ \text{ppt})\ \ (32.2\ \text{ft/sec}^2)\ (18\ \text{ft})}$$

or, $F_n = 0.248$

From equation VI-109 the null zone salinity with a deeper channel will be:

$$\bar{S}_n = \frac{S_o\ 1000\ U_r^2}{S_o\ 0.7\ F_n^2\ gd}$$

$$= (1000)\ (0.5\ \text{ft/sec})^2 / 0.7\ (0.248)^2\ (32.2\ \text{ft/sec}^3)\ (30\ \text{ft})$$

$$\bar{S}_n = 6.0\ \text{ppt}$$

From the prevous tabulation this will occur approximately 65,000 ft from the mouth of the estuary.

Under winter flow conditions,

$$\bar{S}_n = \frac{1000\ U_r^2}{0.7\ F_n^2\ gd}$$

$$= (1000)\ (1.8\ \text{ft/sec}) / 0.7\ (0.248)^2\ (32.2\ \text{ft/sec}^2)\ (30\ \text{ft})$$

$$\bar{S}_n = 77.9\ \text{ppt}$$

This $\bar{S}_n$ is greater than ocean salinity and will not actually be encountered. Thus, null zone shoaling will occur at the mouth if it occurs at all. This condition is common for rivers with seasonally variable flow rates.

END OF EXAMPLE VI-19

REFERENCES

Abramovich, G., 1963. The Theory of Turbulent Jets, MIT Press.

American Public Health Association, 1976. Standard Methods for the Examination of Water and Wastewater. Fourteenth edition.

APHA, AWWA, WPCF, 1980. Standard Methods For the Examination of Water and Wastewater. Fifteenth Edition. APHA, Washington, D.C., 1134 pp.

Austin, R.W., 1974. "Problems in Measuring Turbidity as a Water Quality Parameter," Proceedings of Seminar on Methodology for Monitoring the Marine Environment. EPA Environmental Monitoring Series, Number EPA 600/4-74-004.

Beyer, G.L., 1969. "Turbidimetry and Nephelometry," Encyclopedia of Chemical Technology, New York, pp. 738-798.

Brooks, N.H., 1972. Dispersion in Hydrologic and Coastal Environments. California Institute of Technology, Division of Engineering and Applied Science, Report No. KH-R-29.

California State Water Resources Control Board, 1978. Water Quality Control Plan for Ocean Waters of California. State Water Resources Control Board Resolution No. 78-2. 15 pp.

Carhart, R.A., A.J. Policastro, S. Ziemer, K. Haake, and W. Dunn, 1981. Studies of Mathematical Models for Characterizing Plume and Drift Behavior from Cooling Towers, Volume 2: Mathematical Model for Single-Source (single-tower) Cooling Tower Plume Dispersion. Electric Power Research Institute, CS-1683, Vol. 2, Research Project 906-1.

Chen, C.W. and Orlob, G.T., 1975. "Ecologic Simulation for Aquatic Environments", Systems Analysis and Simulation in Ecology, Vol. III. Academic Press, Inc., New York, pp. 475-558.

DeFalco, Paul, Jr., 1967. "The Estuary-Septic Tank of the Megalopolis," Estuaries; Ed: G.H. Lauff, American Association for the Advancement of Science, Publication No. 83, pp. 701-707.

Duxbury, A.C., 1970. "Estuaries Found in the Pacific Northwest," Proceedings, Northwest Estuarine and Coastal Zone Symposium. Bureau of Sport Fisheries and Wildlife.

Dyer, K.R., 1973. Estuaries: A Physical Introduction, John Wiley and Sons, New York.

Edinger, J.E., 1971. "Estuarine Temperature Distributions," Estuarine Modeling: An Assessment. Chapter 4, Environmental Protection Agency Water Pollution Control Research Series, No. 16070DZV 02/71.

Edinger, J.E. and E.M. Polk, 1969. Initial Mixing of Thermal Discharges into a Uniform Current. Water Center Report #1, Vanderbilt University.

Fan, L.N., 1967. Turbulent Buoyant Jets into Stratified or Flowing Ambient Fluids. KH-R-15, W.M. Keck Laboratory, Cal Tech, Pasadena, California.

Fisher, H.B., 1968. Methods for Predicting Dispersion Coefficients in Natural Streams, with Applications to Lower Reaches of the Green and Duwamish Rivers, Washington. U.S. Geological Survey Professional Paper 582-A, U.S. Government Printing Office, Washington, D.C.

Frick, W.E., 1981a. Projected Area in Plume Modeling. Submitted for publication September 1981. Corvallis, Oregon.

Frick, W.E., 1981b. Comparison of PLUME and OUTPLM Predictions with Observed Plumes. Tetra Tech, Inc.,

Frick, W.E., 1981c. A Theory and Users's Guide for the Plume Model MERGE. Tetra Tech, Inc., Corvallis, Oregon.

Frick, W.E., 1980. Findings and Recommendations On the Use and Modification of the EPA Computer Model DKHPLM. Tetra Tech, Inc., Corvallis, Oregon.

Frick, W.E. and L.D. Winiarski, 1980. Why Froude Number Replication Does Not Necessarily Ensure Modeling Similarity. In: Proceedings of the Second Conference on Waste Heat Management and Utilization, Miami Beach, Florida.

Frick, W.E. and L.D. Winiarski, 1975. Comments on "The Rise of Moist Buoyant Plumes." Journal of Applied Meteorology, Vol. 14, No. 3, page 421.

Giger, R.D., 1972. "Some Estuarine Factors Influencing Ascent of Anadromous Cutthroat Trout in Oregon," Proceedings of the Second Annual Technical Conference on Estuaries of the Pacific Northwest. Oregon State University, pp. 18-30.

Glenne, B., 1967. "A Classification System for Estuaries," Journal of the Waterways and Harbors Division. February, 1967, pp. 55-61.

Goodwin, C.R., E.W. Emmett and B. Glenne, 1970. Tidal Studies of Three Oregon Estuaries. Oregon State University Engineering Experiment Station Bulletin No. 45.

Graham, J.J., 1968. Secchi Disc Observations and Extinction Coefficients in the Central and Eastern North Pacific Ocean. Limnology and Oceanography, pp. 184-190.

Green, J., 1968. The Biology of Estuarine Animals. University of Washington Press; Seattle, Washington.

Hansen, D.V. and M. Rattray, 1966. "New Dimensions in Estuarine Classification," Limnology and Oceanography, Vol. XI(3), pp. 319-326.

Hardy, C.D., 1972. Movement and Quality of Long Island Sound Waters, 1971. State University of New York, Marine Sciences Research Center, Technical Report #17.

Harleman, D.R.F., 1964. "The Significance of Longitudinal Dispersion in the Analysis of Pollution in Estuaries," Proceedings 2nd International Conference on Water Pollution Research. Tokyo, Pergamon Press, New York.

Harleman, D.F.R., 1971. "Hydrodynamic Model - One Dimensional Models." Estuarine Modeling: An Assessment, Chapter II-3, EPA Water Pollution Control Research Series, No. 16070 DZV 02/71, pp. 34-90.

Harleman, D. and C.H. Lee, 1969. The Computation of Tides and Current in Estuaries and Canals. U.S. Corps of Engineers Committee on Tidal Hydraulics, Technical Bulletin No. 16.

Hodkinson, J.R., 1968. "The Optical Measurement of Aerosols," Aerosol Science. Ed: Davies, C.N., Academic Press, Inc., New york, pp. 287-357.

Hough, B.K., 1957. Basic Soils Engineering. The Ronald Press Co., New York, pg. 69.

Hydroscience, Inc., 1971. Simplified Mathematical Modeling of Water Quality. EPA, Water Quality Management Planning Series, Washington, D.C.

Hydroscience, Inc., 1974. Water Quality Evaluation for Ocean Disposal System - Suffolk County, New York. Bowe, Walsh and Associates Engineers, New York.

Ippen, A.T., 1966. Estuary and coastline Hydrodynamics. McGraw-Hill Book Company, New York.

Jirka, G. and D.R.F. Harleman, 1973. The Mechanics of Submerged Multiport Diffusers for Buoyant Discharges in Shallow Water. Report No. 169, Ralph M. Parsons Laboratory, Department of Civil Engineering, MIT, pg. 236.

Johnson, R.G., W.R. Bryant, and J.W. Hedgpeth, 1961. Ecological Survey of Tomales Bay: Preliminary Report of the 1960 Hydrological Survey. University of the Pacific, Pacific Marine Station.

Johnson, J., 1973. "Characteristics and Behavior of Pacific Coast Tidal Inlets," Journal of the Waterways Harbors and Coastal Engineering Division, August, 197, pp. 325-339.

Ketchum, B.H., 1950. "Hydrographic Factors Involved in the Dispersion of Pollutants Introduced Into Tidal Waters," Journal of the Boston Society of Civil Engineers, Vol. 37, pp. 296-314.

Ketchum, B.H., 1955. "Distribution of Coliform Bacteria and Other Pollutants in Tidal Estuaries," Sewage and Industrial Wastes, Vol. 27, pp. 1288-1296.

Ketchum, B.H. and D.J. Keen, 1951. The Exchanges of Fresh and Salt Waters in the Bay of Fundy and in Passamaquoddy Bay. Woods Hole Oceanographic Institution, Contribution No. 593, Reference Number 51-98.

King, H.W., 1954. Handbook of Hydraulics. Revised by E.F. Brater. McGraw-Hill Book Company, New York, pp. 7-33.

McGauhey, P.H., 1968. Engineering Management of Water Quality, McGraw-Hill Book Company, San Francisco.

McKinsey, D., 1974. Seasonal Variations in Tidal Dynamics, Water Quality, and Sediment in Alsea Estuary, Oregon State University, Dept. of Civil Engineering, Corvallis, Oregon.

Mysels, K.J., 1959. Introduction to Colloid Chemistry, Interscience Publisher, New York, pg. 61.

Neumann, G. and W. Pierson, 1966. Principles of Physical Oceanography, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

O'Brien, M.P., 1969. "Equilibrium Flow Areas of Inlets on Sandy Coasts," Journal of the Waterways and Harbors Division, Proceedings of the American Society of Civil Engineers, pp. 43-51.

O'Connor, D.J., 1965. Estuarine Distribution of Nonconservative Substances. Journal of Sanitary Engineering Division, ASCE. SA1, pp. 23-42.

O'Connor, D.J. and R.V. Thomann, 1971. "Water Quality Models: Chemical, Physical, and Biological Constituents," Estuarine Modeling: An Assessment, Chapter III, EPA Water Pollution Control Research Series No. 16070 DZV 02/71, pp. 102-169.

Parker, F.L. and P.A. Krenkel, 1970. CRC Physical and Engineering Aspects of Thermal Pollution, The Chemical Rubber Company Press, Cleveland, Ohio.

Pearson, E. et al., 1967. Final Report: A Comprehensive Study of San Francisco Bay, Volume V: Summary of Physical, Chemical and Biological Water and Sediment Data, U.C. Berkeley Sanitary Engineering Research Laboratory, Report No. 67-2.

Perkins, E.J., 1974. The Biology of Estuaries and Coastal Waters, Academic Press, London.

Peterson, O.H. et al., 1975. "Location of the Non-tidal Current Null Zone in Northern San Francisco Bay." Estuarine and Coastal Marine Science, (1975) 3, pp. 1-11.

Policastro, A.J., R.A. Carhart, S.E. Ziemer, and K. Haake, 1980. Evaluation of Mathematical Models for Characterizing Plume Behavior from Cooling Towers. Dispersion from Single and Multiple Source Natural Draft Cooling Towers, NUREG/CR-1581, Vol. 1, Argonne National Laboratory, Argonne, Illinois.

Pritchard, D.W., 1960. "The Movement and Mixing of Contaminants in Tidal Estuaries," Proceedings of the First International Conference on Waste Disposal in the Marine Environment, University of California, Berkeley.

Pritchard, D.W., 1967. "What is an Estuary: Physical Viewpoint," Estuaries. Ed: Lauff, G.H., American Association for the Advancement of Science, Publication No. 83, pp. 2-6.

Pritchard, D.W., 1969. Dispersion and Flushing of Pollutants in Estuaries. Journal of Hydraulics Division, ASCE, HY1, pp. 115-124.

Pritchard, D.W. and J.R. Schubel, 1971. "What is an Estuary," The Estuarine Environment-Estuaries and Estuarine Sedimentation, American Geological Institute.

Rawn, A.M., F.R. Bowerman, and N.H. Brooks, 1960. Diffusers for Disposal of Sewage in Seawater. Journal of the Sanitary Engineering Division, ASCE, SAR, pg. 80.

Schubel, J.R., 1971. "The Origin and Development of Estuaries," The Estuarine Environment-Estuaries and Estuarine Sedimentation, American Geological Institute.

Schultz, E.A. and H.B. Simmons, 1957. Freshwater-Salt Water Density Current, a Major Cause of Siltation in Estuaries. Commission on Tidal Hydraulics, U.S. Army Corps of Engineers, Technical Bulletin No. 2.

Serne, R.J. and B.W. Mercer, 1975. "Characterization of San Francisco Bay Delta Sediments - Crystalline Matrix Study." Dredge Disposal Study of San Francisco Bay and Estuary, Appendix F, U.S. Army U.S. Corps of Engineers, San Francisco, District.

Shiraza, M.A. and L.R. Davis, 1976. Workbook of Thermal Plume Predictions: Surface Discharge, USEPA Corvallis Environmental Research Laboratory, Oregon.

Silvester, R., 1974. Coastal Engineering, II: Sedimentation, Estuaries, Tides, Effluents and Modeling, Elsevier Scientific Publishing Company, New York.

Stommel, H., 1953. "Computation of Pollution in a Vertically Mixed Estuary." Sewage and Industrial Wastes, 25(9), pp. 1065-1071.

Streeter, V.L. (Editor-in-Chief), 1961. Handbook of Fluid Dynamics, McGraw-Hill Book Company, Inc., New York, New York.

Stumm, W. and J.J., Morgan, 1970. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters, Wiley-Interscience, New York, pp. 507-513.

Teeter, A.M. and D.J. Baumgartner, 1979. Prediction of Initial Mixing for Municipal Ocean Discharges, CERL-043. USEPA Corvallis Environmental Research Laboratory, Oregon.

Tesche, T.W., W.D. Jensen, and J.L. Haney, 1980. Modeling Study of the Proposed SMUD Geothermal Power Plant: Model Application Protocol. SAI No. 118-E780-11, Systems Applications, Inc., San Rafael, California.

Tetra Tech, Inc., 1979. Methodology for Evaluation of Multiple Power Plant Cooling System Effects. Volume: General Description and Screening. Electric Power Research Institute Report EA-1111. Palo, Alto, California

Tracor, 1971. Estuarine Modeling: An Assessment For: Water Quality Office, Environmental Protection Agency.

U.S. Engineer District - San Francisco, 1975. Draft Composit Environmental Statement for Maintenance Dredging of Federal Navigation Projects in San Francisco Bay Region, California, U.S. Army Corps of Engineers.

U.S. Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.

Van de Hulst, H.C., 1957. Light Scattering by Small Particles. John Wiley and Sons, Inc., New York.

Winiarski, L.D., and W.E. Frick, 1978. Methods of Improving Plume Models. Presented at the May 2-4, 1978, Cooling Tower Environment 1978 Conference, University of Maryland, College Park, Maryland.

Winiarski, L.D. and W.E. Frick, 1976. Cooling Tower Plume Model, EPA-600/3-76-100. USEPA Corvallis Environmental Research Laboratory, Corvallis, Oregon.

APPENDIX A

MONTHLY DISTRIBUTION OF RAINFALL EROSIVITY FACTOR R

Figure A-1 - Key Map for Selection of Distribution Curves for Eastern United States

Figure A-2a through A-2i - Distribution Curves for Eastern United States

Distribution Curves for Hawaii (Figures A-3a through A-3c)

Methods for Developing R Distribution Curves for the Western United States

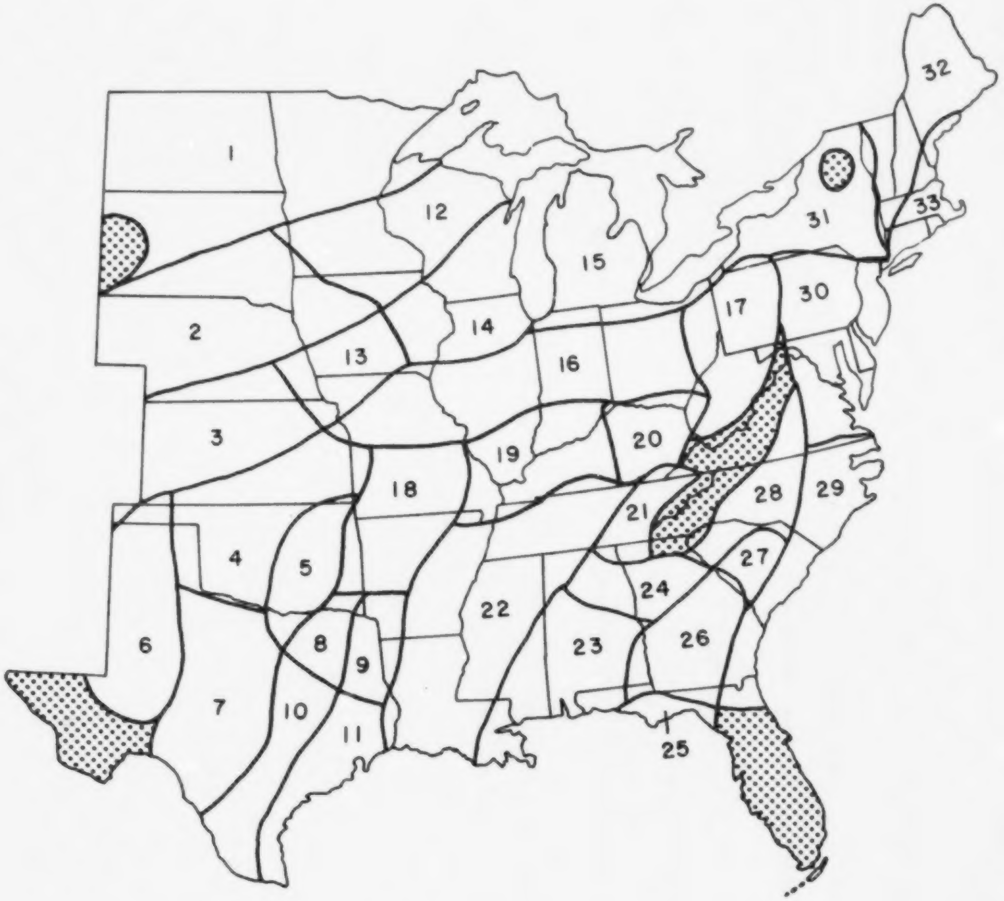


FIGURE A-1 KEY MAP FOR SELECTION OF APPLICABLE EROSION-INDEX DISTRIBUTION CURVE (WISCHMEIR AND SMITH, 1965)

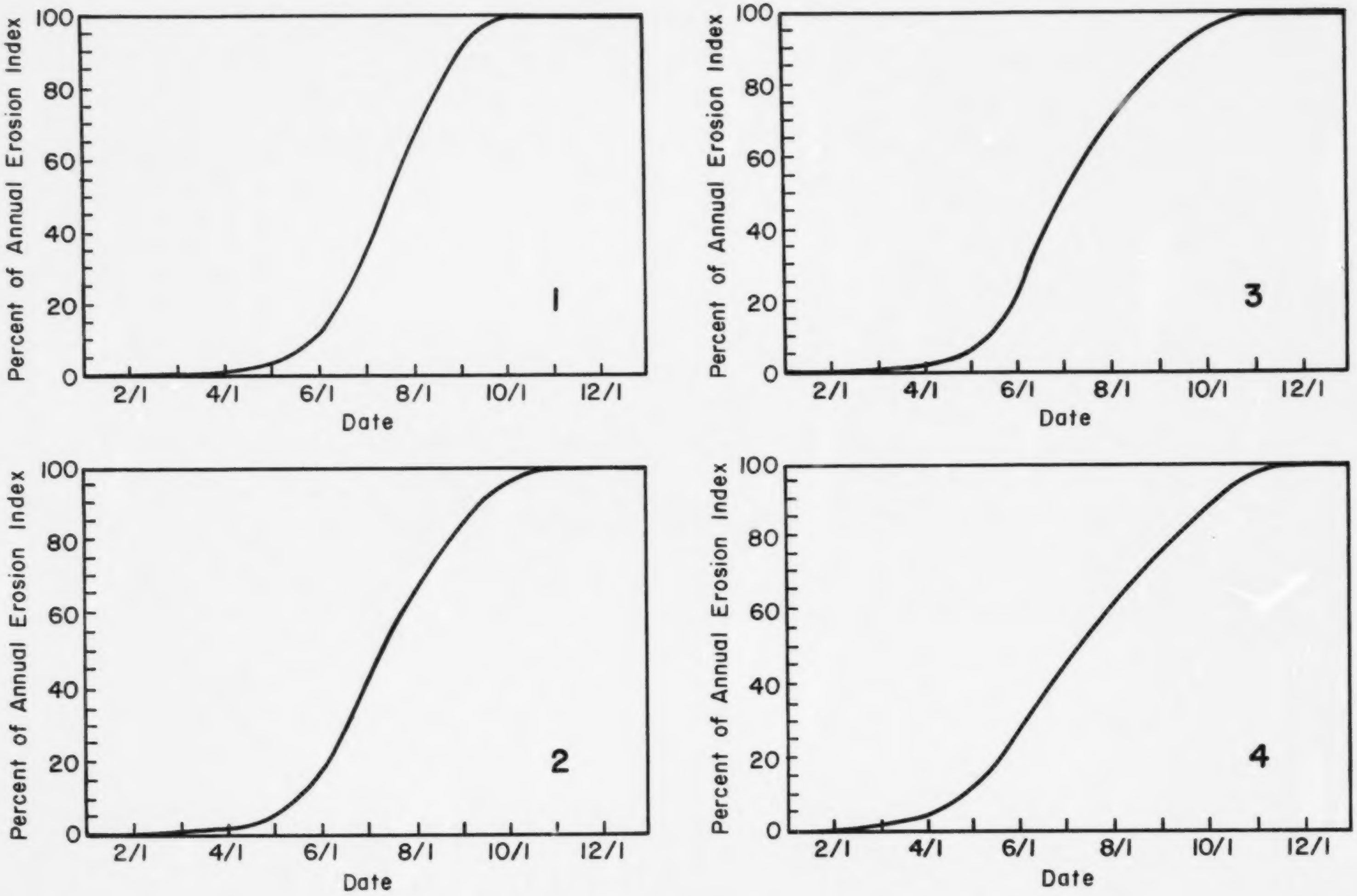


FIGURE A-2A EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

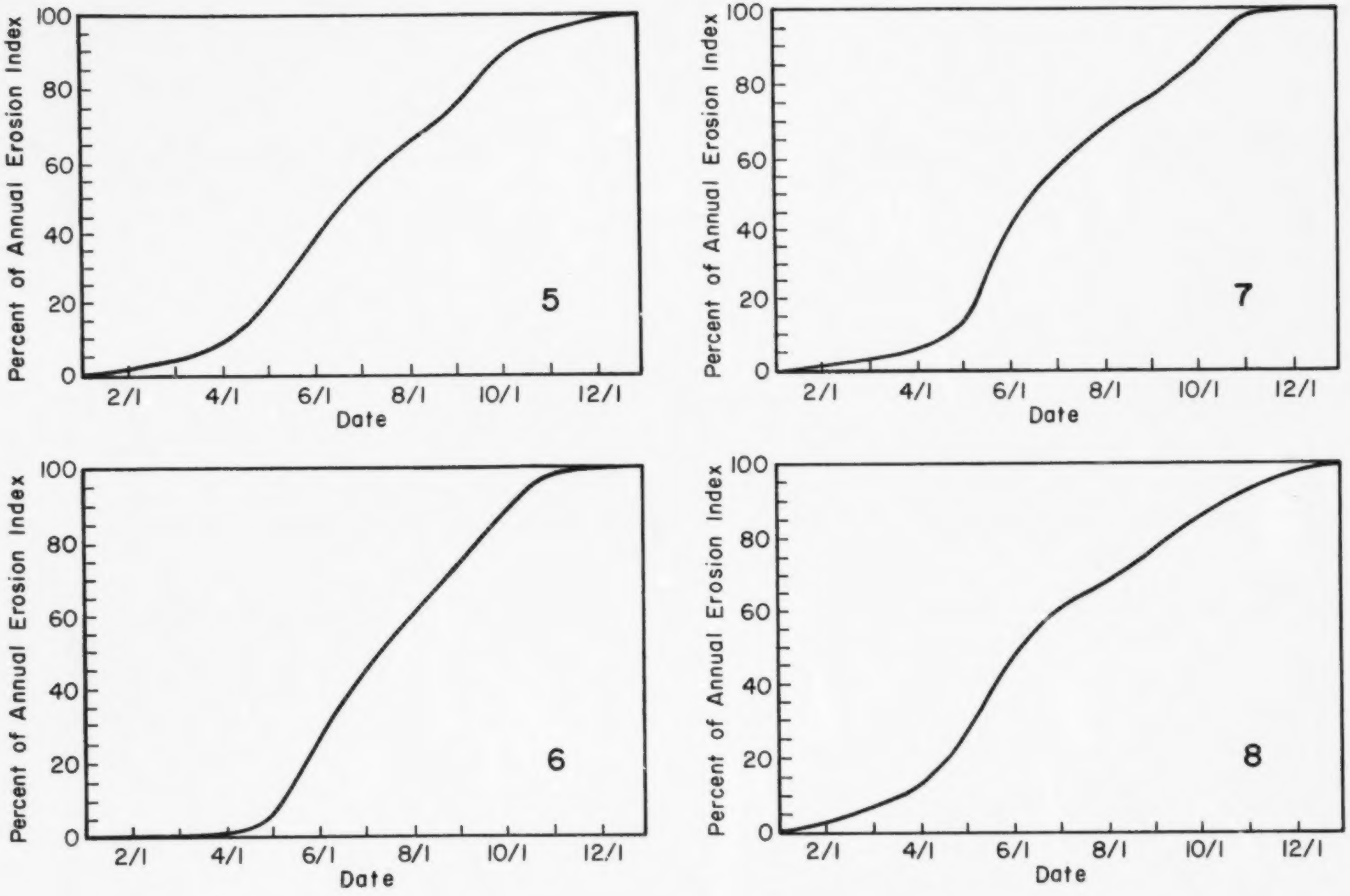


FIGURE A-2B EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

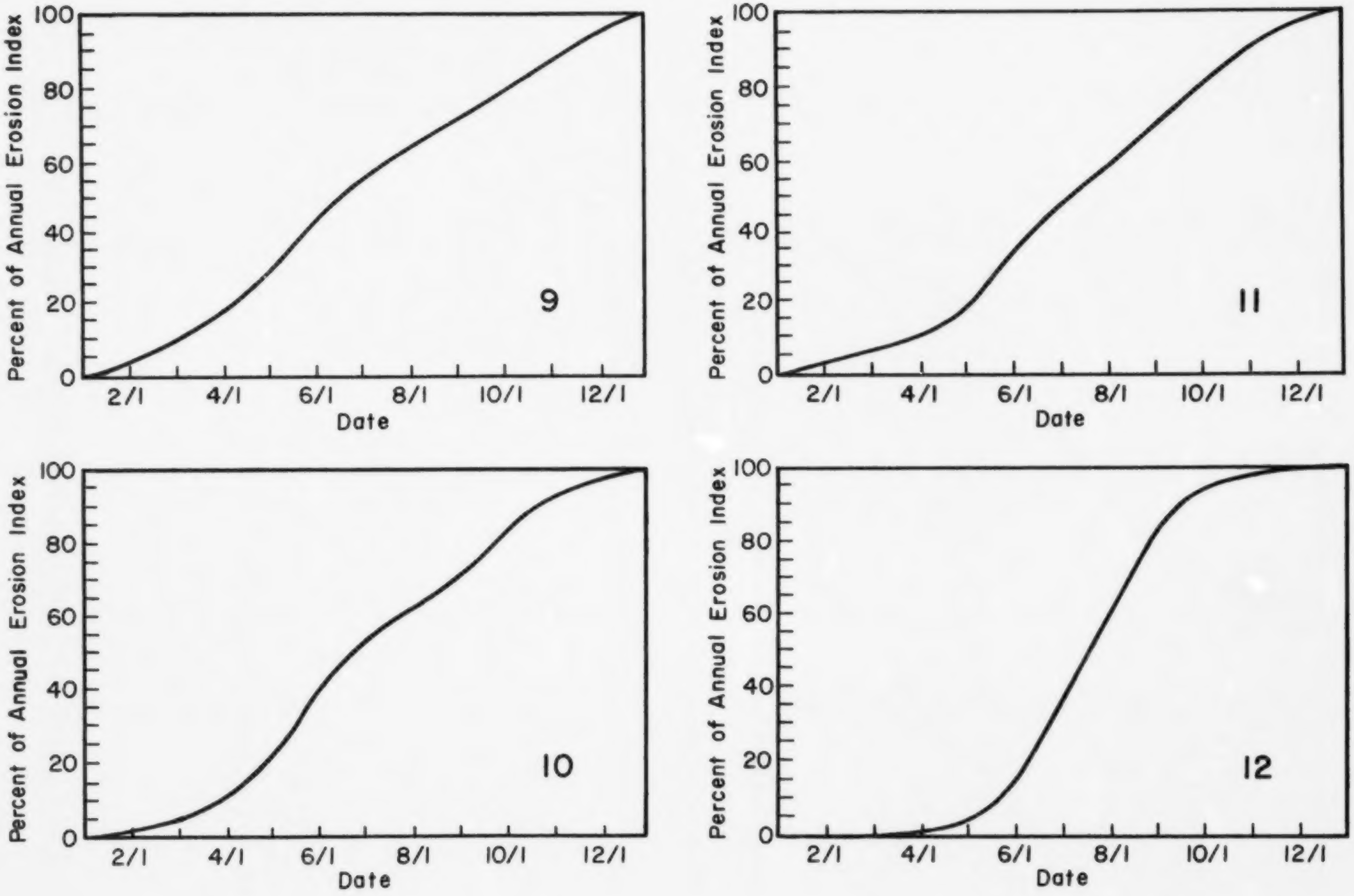


FIGURE A-2C EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

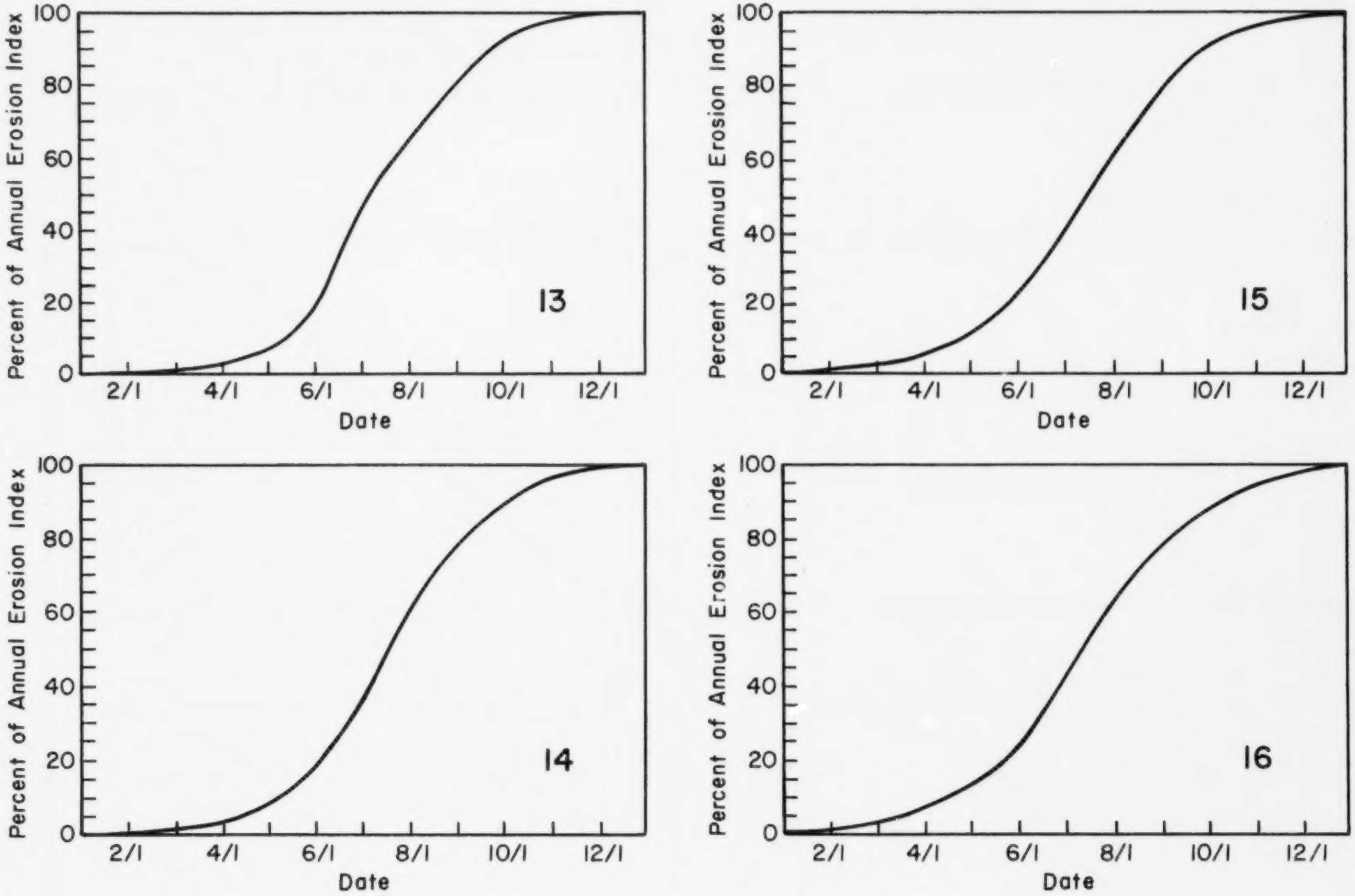


FIGURE A-2D EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

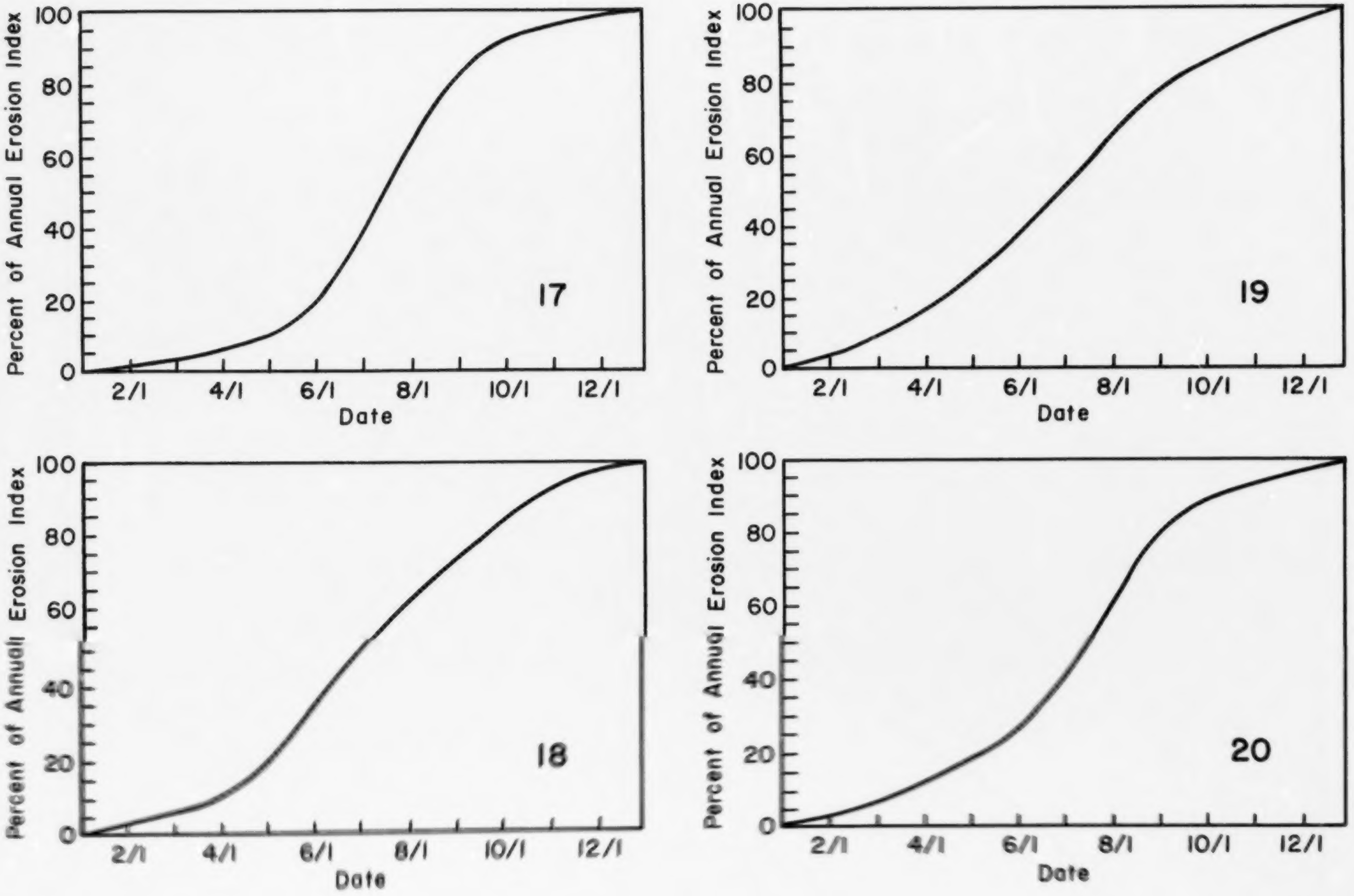


FIGURE A-2E EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

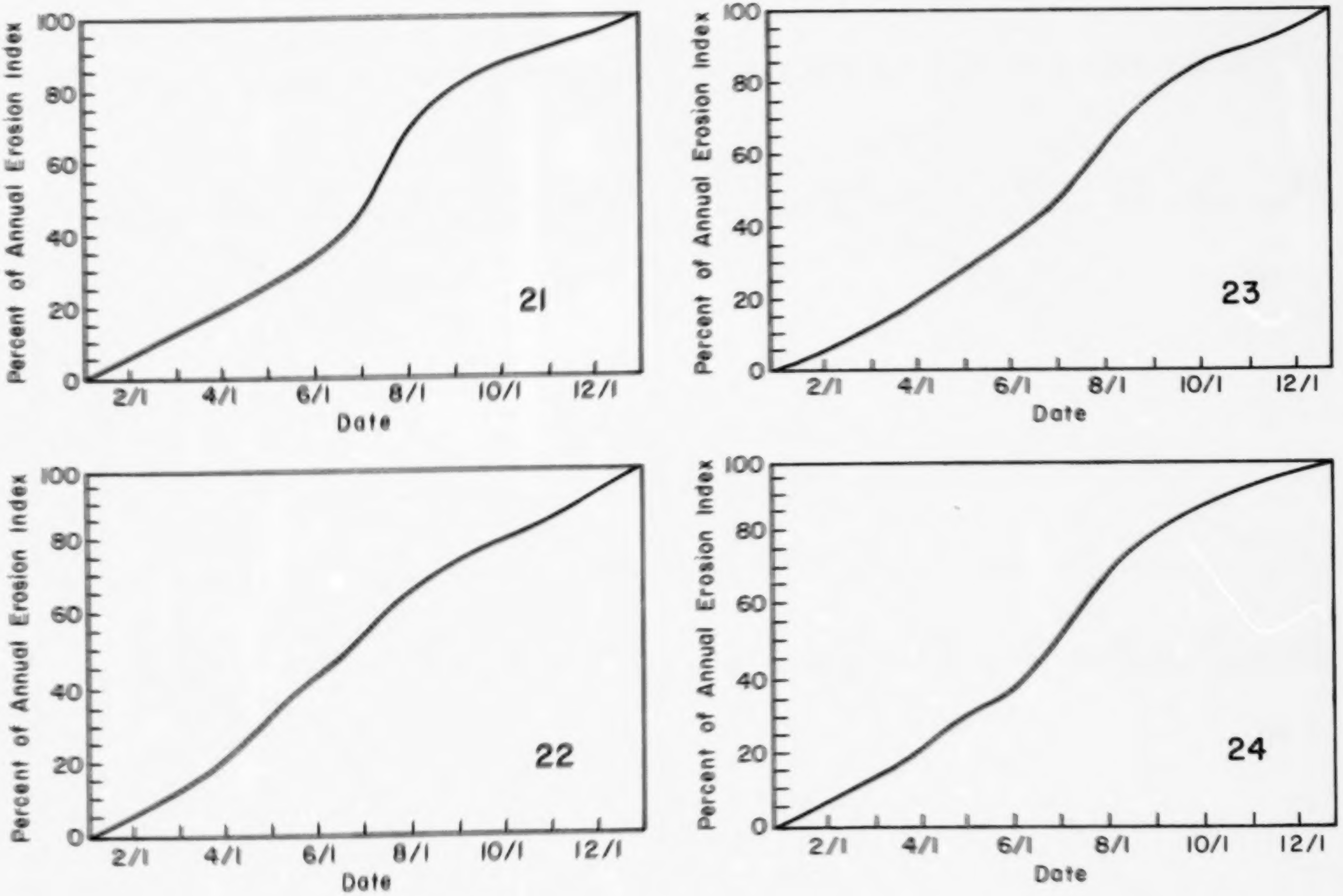


FIGURE A-2F EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

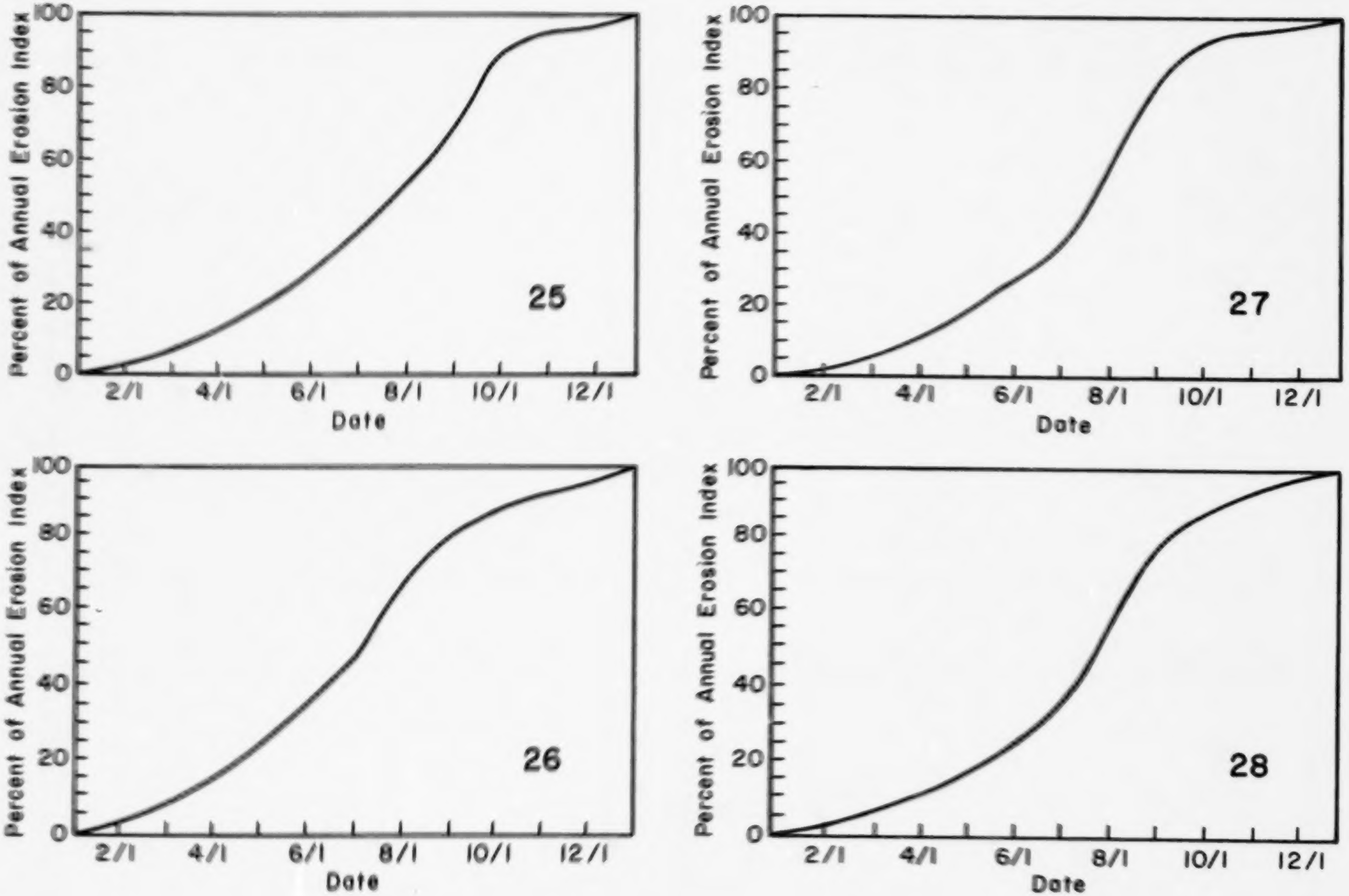


FIGURE A-2G EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

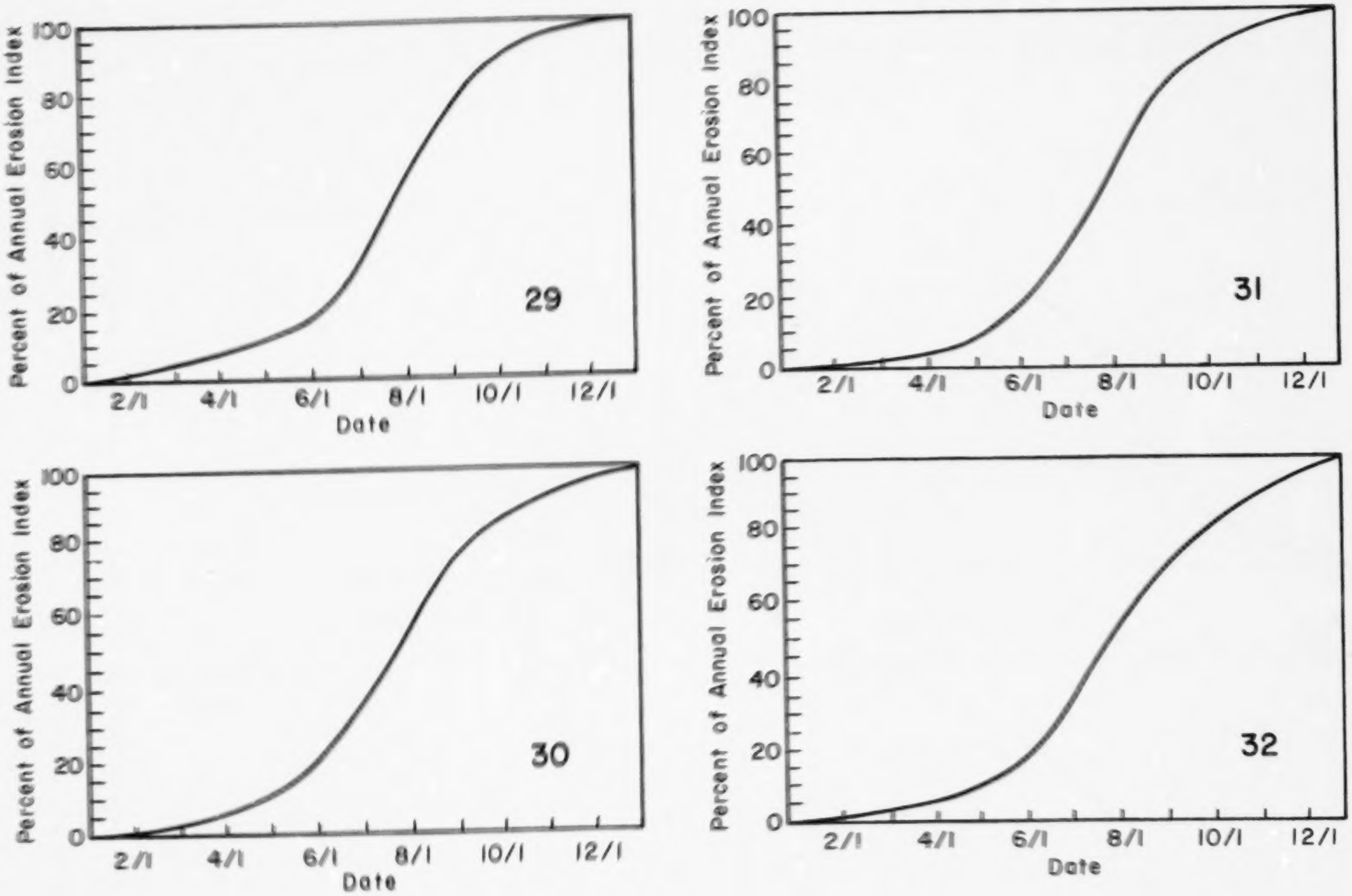


FIGURE A-2H EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

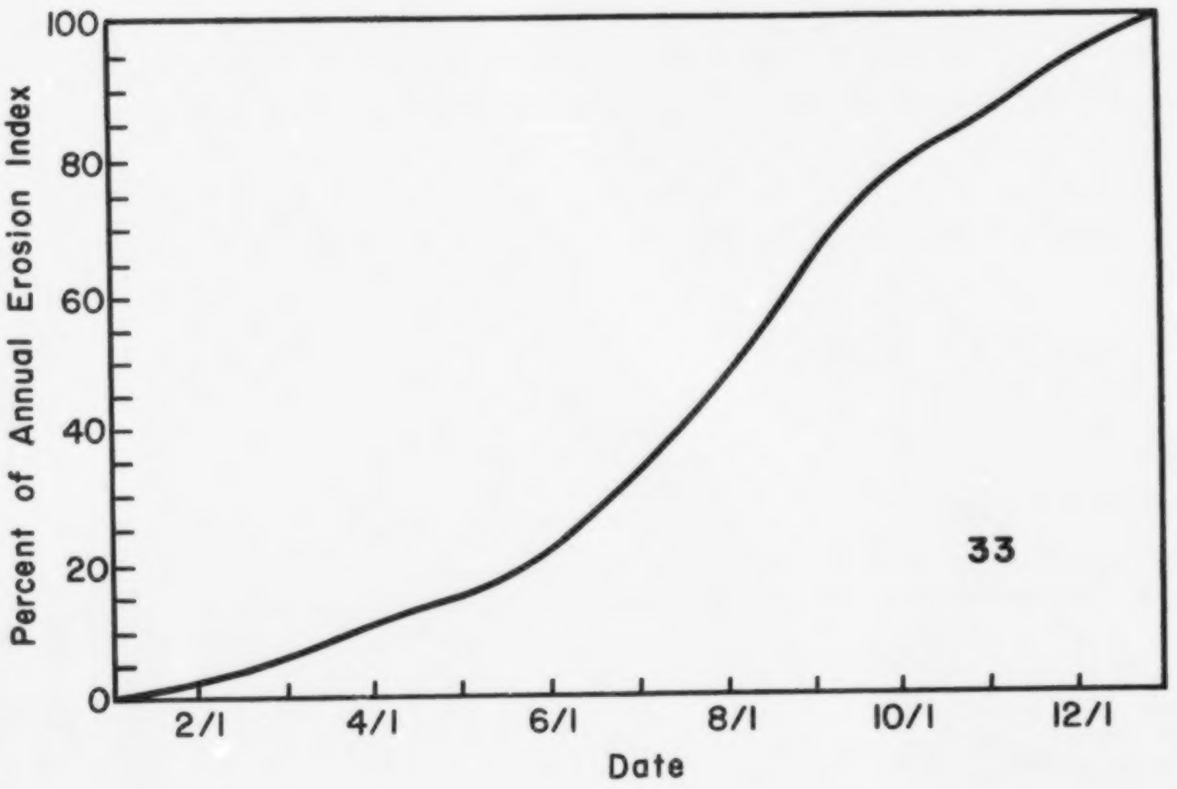


FIGURE A-21 EROSION-INDEX DISTRIBUTION CURVES FOR THE EASTERN UNITED STATES (WISCHMEIER AND SMITH, 1965)

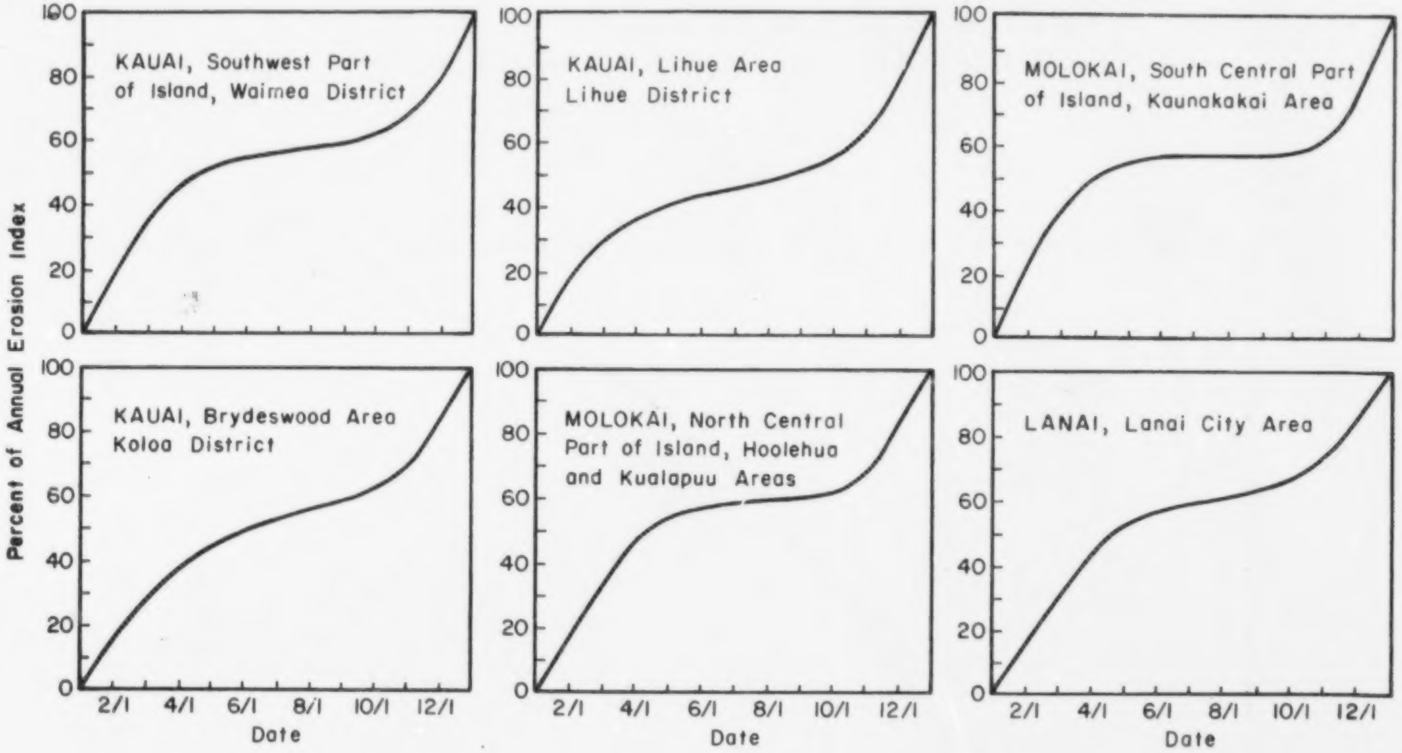


FIGURE A-3A EROSION-INDEX DISTRIBUTION CURVES FOR HAWAII
(SOILS TECHNICAL NOTE NO. 3, 1974)

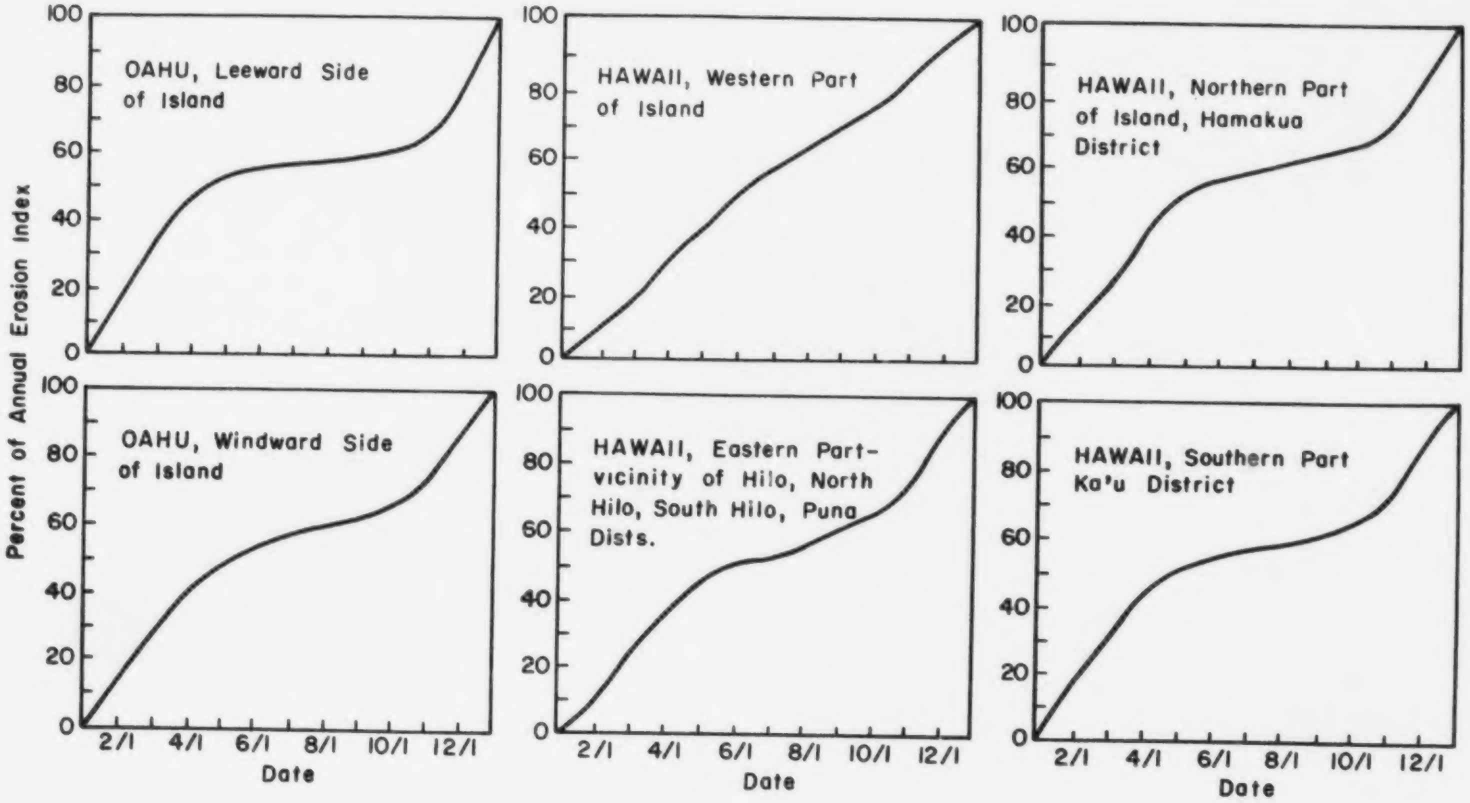


FIGURE A-3B EROSION-INDEX DISTRIBUTION CURVES FOR HAWAII
(SOILS TECHNICAL NOTE NO. 3, 1974)

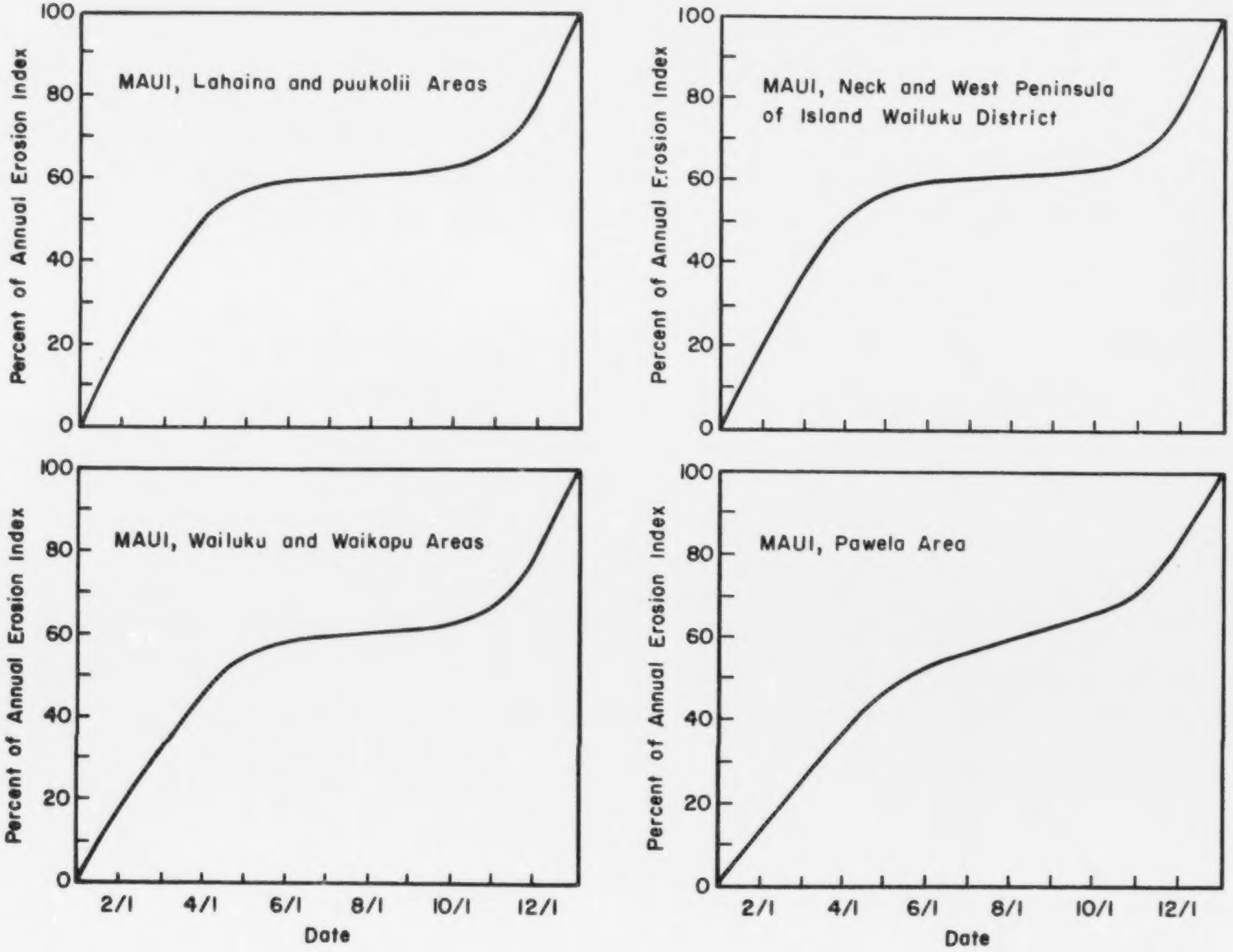


FIGURE A-3C EROSION-INDEX DISTRIBUTION CURVES FOR HAWAII
(SOILS TECHNICAL NOTE NO. 3, 1974)

METHODS FOR DEVELOPING R DISTRIBUTION CURVES FOR THE WESTERN UNITED STATES (Conservation Agronomy Technical Note No. 32, 1974)

R_s is significant in portions of this area. Divide the annual R_r for the location by the average annual precipitation to obtain a factor. Multiply each month's precipitation by this factor to obtain monthly R_r values. Add the prorated monthly R_s values to R_r for the months when snowmelt occurs, to obtain the monthly R values. Compute the monthly accumulative percent. The following example is for Hylton, in Elko County, Nevada. The 2-6 rainfall for this area is 0.9 in. The annual R_r determined from the Type II curve on Figure III-4, is 18. Annual precipitation average is 12.72 in. Factor is 18 ÷ 12.72 = 1.42.

Monthly precipitation (water depth) for December through March is 4.92 in. R_s = 4.92 x 1.5 = 7.38. This is prorated, based on local judgment to

January 10%	or	0.7
February 20%	or	1.5
March 50%	or	3.7
April 20%	or	1.5

					Cumulative	
Month (1)	Precipitation (Inches Water Depth) (2)	R_r (3)	R_s (4)	R* (5)	R (6)	% (7)
January	1.18	1.68	0.7	2.38	2.38	0.093
February	1.14	1.62	1.5	3.12	5.50	21.6
March	1.29	1.83	3.7	5.53	11.03	43.3
April	1.49	2.12	1.5	3.62	14.65	57.5
May	1.48	2.10	-	2.10	16.75	65.8

---

*Columns (3) + (4).

Month (1)	Precipitation (Inches Water Depth) (2)	R_r (3)	R_s (4)	R* (5)	Cumulative R (6)	Cumulative % (7)
June	0.91	1.29	-	1.29	18.04	70.9
July	0.63	0.89	-	0.89	18.93	74.4
August	0.52	0.74	-	0.74	19.67	77.3
September	0.63	0.89	-	0.89	20.56	80.8
October	1.17	1.66	-	1.66	22.22	87.3
November	0.97	1.38	-	1.38	23.60	92.7
December	1.31	1.86	-	1.86	25.46	100.

---

*Columns (3) + (4).

Values in cumulative percent column (7) are the points used in plotting the monthly R distribution curve.

For A-2, A-3, and A-4 Areas Shown in Figure III-4

R_s is not significant in most parts of these areas. Use the monthly rainfall distribution as the R distribution. Simply accumulate monthly precipitation amounts and divide each by the annual precipitation. The results obtained for each month will be the points for plotting the monthly R distribution curve.

For B-1 and C Areas Shown in Figure III-4

R_s in most parts of these areas is significant.

1. "Multipliers" are used to time average monthly precipitation amounts. Sum the results of multiplications to obtain the "factored annual precipitation". Divide the annual R_r for

the location by the "factored annual precipitation" to obtain a factor which will be used to convert monthly precipitation amounts to the monthly R values (see the previous section for A-1 area). Values of multipliers are:

Month(s)	Multipliers
January, February, March	0.1
April	1.0
May	4.0
June, July, August	7.0
September, October	2.0
November, December	0.1

2. Add the prorated R_s values to the months when the snowmelt occurs to obtain the monthly R values. Compute the monthly cumulative percents which are points used in plotting the monthly R distribution curve. The following example is for a hypothetical area which has an annual rainfall factor R_r of 25, and a R_s factor of 7.5 (4.94 x 1.5 rounded to 7.5). The 4.94 in. is total precipitation for December, January, February, and March. R_s factor is prorated to:

January	0%	or	0 in.
February	33.3%	or	2.5 in.
March	33.3%	or	2.5 in.
April	33.3%	or	2.5 in.

Month (1)	Precipitation (in.) (2)	Multiplier (3)	Factored Monthly pptn. (Col. 2 x Col. 3) (4)	Monthly R_r* (5)
January	1.33	0.1	0.13	0.11
February	1.14	0.1	0.11	0.09
March	1.35	0.1	0.13	0.11
April	1.48	1.0	1.48	1.24
May	1.43	4.0	5.72	4.80
June	1.00	7.0	7.00	5.78
July	0.80	7.0	5.60	4.69
August	0.78	7.0	5.46	4.58
September	0.85	2.0	1.70	1.43
October	1.14	2.0	2.28	1.91
November	0.92	0.1	0.09	0.08
December	1.12	0.1	0.11	0.09
Total	13.34		29.81	25.0

Month (1)	Monthly R_s (6)	Monthly R $=R_r + R_s$ (7)	Cumulative R (8)	Cumulative % (9)
January	-	0.11	0.1	-
February	2.5	2.59	2.7	8
March	2.5	2.66	5.4	17
April	2.5	3.74	9.1	28
May	-	4.80	13.9	43
June	-	5.87	19.8	61
July	-	4.69	24.5	75
August	-	4.58	29.0	89
September	-	1.43	30.5	94
October	-	1.91	32.4	99
November	-	0.08	32.4	100
December	-	0.09	32.5	100
Total	7.5	32.5		

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*In this example, the calculated factor value is 0.84 (25 + 29.81). Monthly R_r is obtained by multiplying each "factored monthly pptn." with 0.84.

For B-2 Area Shown in Figure III-3

In this area, no R_s values are needed. Follow the same procedure and use the same set of multipliers as the preceding section for areas B-1 and C, except that steps for obtaining monthly R_s values are not used. The cumulative R and cumulative percent are computed from monthly R_r (column 5 in the preceding example).

REFERENCES FOR APPENDIX A

Conservation Agronomy Technical Note No. 32, U.S. Department of Agriculture, Soil Conservation Service, West Technical Service Center, Portland, Oregon, September, 1974.

Soils Technical Note No. 3, U.S. Department of Agriculture, Soil Conservation Service, Honolulu, Hawaii, May, 1974.

Wischmeier, W.H., and Smith, D.D., "Predicting Rainfall--Erosion Losses from Cropland East of the Rocky Mountains," Agricultural Handbook 282, U.S. Department of Agriculture, Agriculture Research Service, May, 1965.

APPENDIX B

METHODS FOR PREDICTING SOIL ERODIBILITY INDEX K

Nomograph for Predicting K Values of Surface Soils Using Chemical and Physical Parameters.

Nomograph for Predicting K Values of High Clay Subsoils Using Chemical Mineralogical and Physical Parameters.

NOMOGRAPH FOR PREDICTING K VALUES OF SURFACE SOIL

In 1971 Wischmeier, et al. (1971) presented a soil erodibility nomograph derived from statistical analysis of 55 soil types. Five soil parameters are included in the nomograph to predict erodibility: percent silt plus very fine sand; percent sand greater than 0.10 millimeter; organic matter content; soil structure; and permeability. Values of the parameters may be obtained from routine laboratory determinations and standard soil profile descriptions.

The nomograph is reproduced here as Figure B-1.

Description of Factors (Water Resources Administration, 1973)

Grain Size Distribution

Grain size distribution has a major influence on a soil's erodibility: the greater the silt content, the greater the soil's erodibility; the smaller the sand content, the greater the soil's erodibility.

Particles in the very fine sand classification behave more like silt than sand. Therefore, the percentage of very fine sand should be subtracted from the total percentage of sand and added to the percentage of silt.

Organic Matter

The percentage of organic matter was determined, in work by Wischmeier, et al., by the Walkley-Black method (Walkley and Black, 1934). The organic matter content is approximately 1.72 times the percent carbon. Soil erodibility decreases as organic matter content increases.

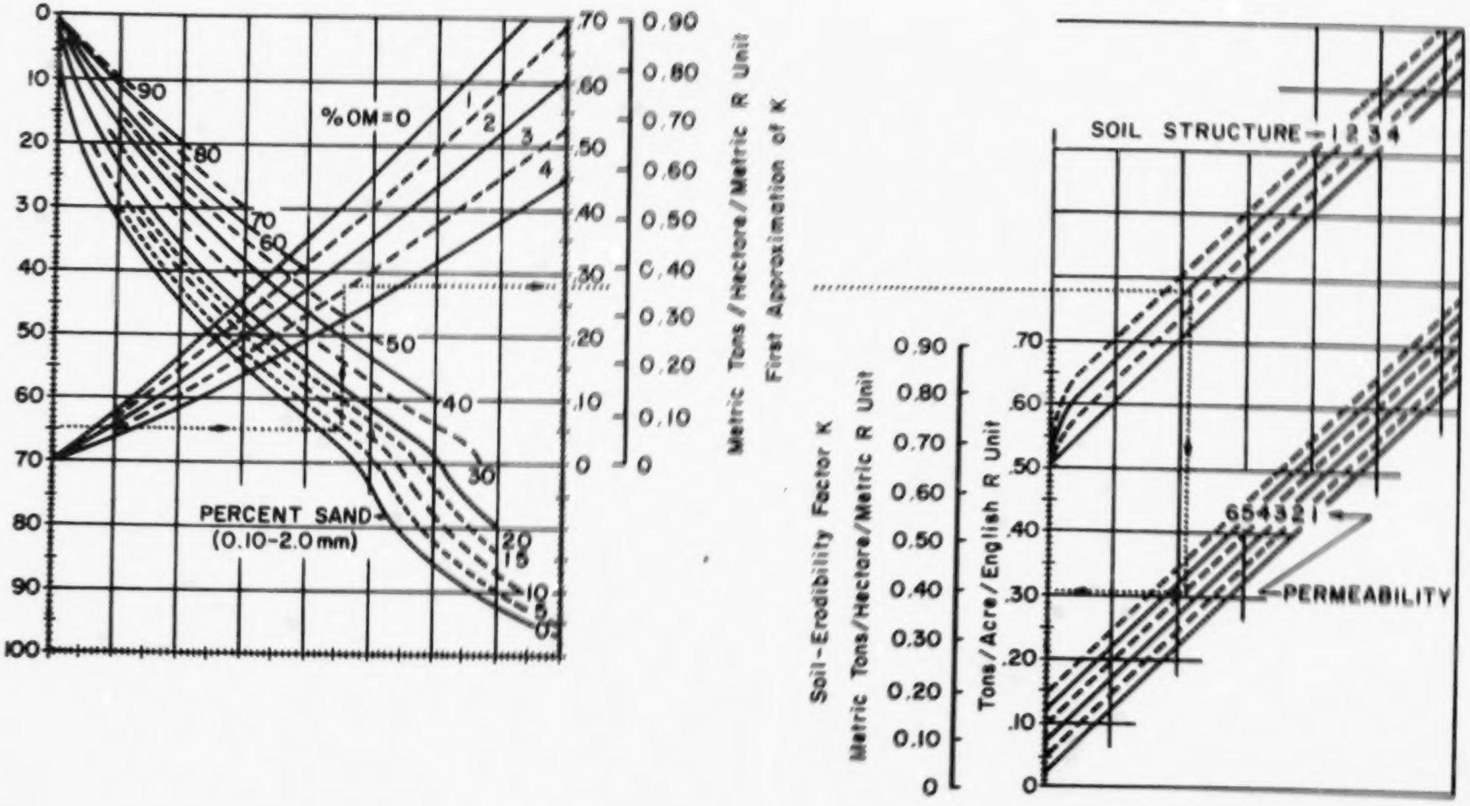

FIGURE B-1 SOIL ERODIBILITY NOMOGRAPH (WISCHMEIER ET AL., 1971)

Soil Structure

The soil structure is descriptive of the overall arrangement of the soil solids. The four parameter values and their descriptions are as follows:

Parameter Value	Descriptions
	Granular - All rounded aggregates may be placed in this category. These rounded complexes usually lie loosely and are readily shaken apart. When wetted, the voids are not closed readily by swelling.
1	Very fine granular - less than 1 mm.
2	Fine granular - 1 to 2 mm.
3	Medium granular - 2 to 5 mm.
3	Coarse granular - 5 to 10 mm.
4	Blocky - Aggregates have been reduced to blocks, irregularly six-faced, and with their three dimensions more or less equal. In size, the fragments range from a fraction of an inch to 3 or 4 in. in thickness.
4	Platy - Aggregates are arranged in relatively thin plates or lenses.
4	Prismatic - Aggregates or pillars are vertically oriented, with tops plane, level, and clean cut. They commonly occur in subsoils of arid and semi-arid regions.

Parameter Value	Descriptions
4	Columnar - Aggregates or pillars are vertically oriented, with rounded tops. They commonly occur when the soil profile is changing and the horizons are degrading.
4	Massive - Soil units are very large, irregular, featureless as far as characteristic aggregates are concerned.

Soil Permeability

Soil permeability is the ability of the soil to transmit water. Since different soil horizons vary in permeability, the relative permeability classes refer to the soil profile as a whole. The relative permeability classes are as follows:

Class	Permeability Rates in In/Hour	
1	Rapid	over 6.0
2	Moderately rapid	2.0 to 6.0
3	Moderate	0.6 to 2.0
4	Moderately slow	0.2 to 0.6
5	Slow	0.06 to 0.2
6	Very slow	less than 0.06

Reading the Nomograph

Entry values for all of the nomograph curves, except permeability class, are for the upper 6 or 7 in. of soil. For soils in cuts, the entry values are for the upper 6 or 7 in. of the newly exposed layer. In reading the nomograph, interpolate linearly between adjacent curves when the entry data do not coincide with the plotted curves of percent sand or percent organic matter. The percent of coarse fragments may be significant and is not included in the nomograph. Therefore, reduce the value of K read from the nomograph by 10% for soils with stratified subsoils that include layers of small stones or gravel without a seriously impeding layer above them.

Enter the left scale of the nomograph with the appropriate percent silt plus very fine sand, move horizontally to intersect the correct percent-sand curve (interpolating to the nearest percent), vertically to the correct organic matter curve, and then horizontally to the right scale for first approximation of soil erodibility.

For soils having a fine granular structure and moderate permeability, the value of K can be obtained directly from this scale. However, if the soil is other than of fine granular structure, or permeability is other than moderate, it is necessary to proceed to the second part of the nomograph, horizontally to intersect the correct structure curve, vertically downward to the permeability curve, and horizontally to the soil erodibility index scale.

NOMOGRAPH FOR PREDICTING K VALUES OF HIGH CLAY SUBSOILS

Subsoils are commonly heavier in texture than the surface soils. In addition, subsoils likely have aggregating agents that are very much different from those found in surface soils and the degree of aggregation is known to have a profound influence on erodibility.

From an EPA study (Roth, et al., 1974) conducted at Purdue University, a multiple linear regression equation and nomograph were developed which can be used to estimate the erodibility factor, K, of many high clay soils. Multiple regression analysis revealed that amorphous iron, aluminum and silicon hydrous oxides serve as soil stabilizers in subsoils (whereas, organic matter is the major stabilizer in surface soils). The nomograph was developed from the multiple linear regression equation relating the erodibility factor to the soil texture factor, M, the amount of CDB (citrate-dithionite-bicarbonate) extractable iron and aluminum oxides, and the amount of CDB extractable silica.

The equation used to derive the nomograph was:

$$K_{pred} = 0.32114 + 2.0167 \times 10^{-4} M - 0.14440 (\% Fe_2O_3 + \% Al_2O_3) - 0.83686 (\% SiO_2)$$

where

K_{pred} = predicted K value of subsoil

M = soil texture factor, defined by percent new silt (percent new silt + percent new sand). "New" silt has 2 to 100 μm mean diameter. "New" sand has 100 to 2,000 μm mean diameter.

$\% Fe_2O_3$ = percent CBD extractable iron oxide of soil.

$\% Al_2O_3$ = percent CDB extractable aluminum oxide of soil.

$\% SiO_2$ = percent CDB extractable silica in soil.

The nomograph for estimating the erodibility factor, K, of high clay subsoils is reproduced in Figure B-2.

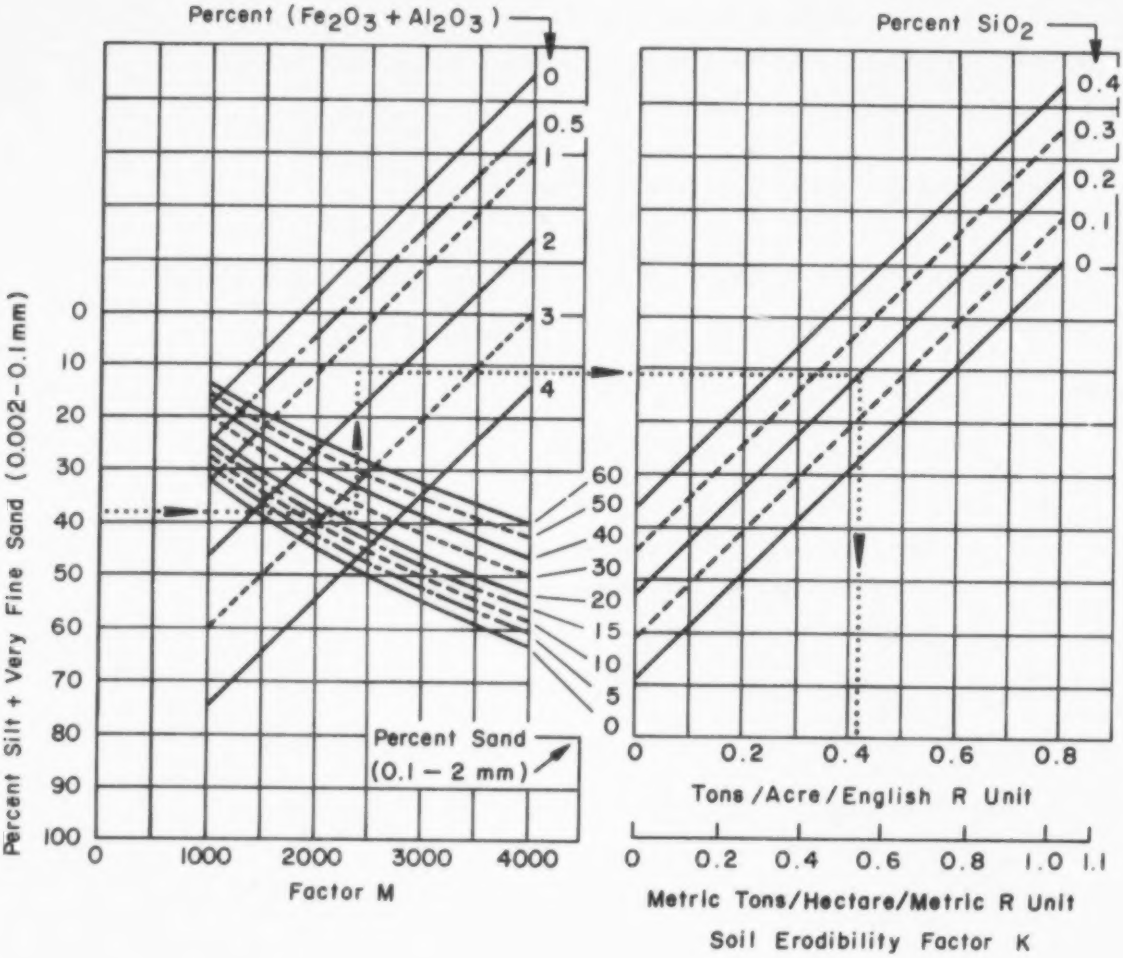

FIGURE B-2 NOMOGRAPH FOR ESTIMATING THE ERODIBILITY FACTOR K OF HIGH CLAY SUBSOILS (ROTH ET AL., 1974)

REFERENCES FOR APPENDIX B

Roth, C.B., Nelson, D.W., and Romkens, M.J.M., 1974. "Prediction of Subsoil Erodibility Using Chemical, Mineralogical, and Physical Parameters," for the U. S. Environmental Protection Agency (EPA-660/2-74-043), Washington, D.C.

Walkley, A., and Black, I.A., 1934. "An Examination of the Degtjareff Method for determining Soil Organic Matter," Soil Sci., 37, pp. 29-38.

Wischmeier, W.H., Johnson, C.B., and Cross, B.U., 1971. "A Soil Erodibility Nomograph for Farmland and Construction Sites," J. Soil and Water Conservation, 26:189-193. "Technical Guide to Erosion and Sediment Control Design (Draft)," 1973. Water Resources Administration, Maryland Department of Natural Resources, Annapolis, Maryland.

APPENDIX C

STREAM AND RIVER DATA

Table C-1	Stream and River Reaeration and Deoxygenation Rates (From Hydroscience, 1971)
Table C-2	Deoxygenation Rate Constants (From Bansal, 1975)
Table C-3	Alluvial Channel and Sediment Data (From Schumm, 1960)

TABLE C-1

STREAM AND RIVER REAERATION AND DEOXYGENATION RATES (FROM HYDROSCIENCE, 1971)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Grand River (Michigan)	Shallow	1.9	320.0	295.	0.92	4.5	0.59
Clinton River (Michigan)	Shallow	1.58	44.6	33.	0.72	5.9	3.37
Truckee River (Nevada)	Shallow	1.67	150.	180.	1.20	5.6	0.36
		1.67	150.	195.	1.30	5.7	0.36
		1.67	150.	271.	1.81	6.6	0.96
Flint River (Michigan)	Shallow	2.1	210.	134.	0.64	3.5	0.56
		2.6	200.	174.	0.83	3.9	0.63
		2.6	400.	174.	0.44	3.1	0.69
		1.7	290.	204.	0.73	5.0	0.69
		1.9	400.	204.	0.51	2.2	0.69
Jackson River (Virginia)	Shallow	3	365.	100.	0.27	4.1	1.25
N. Branch Potomac River (Md., W.Va.)	Shallow	2	100.	100.	1.0	9.0	0.40

TABLE C-1 (continued)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Clarion River (Penna.)	Shallow	1		1 - 10.			3
		1.9			0.55	2.26	
South River		1-2		35.			2
Ivel River (England)	Shallow	1.21		4.86	0.14	2.35	
		1.51		4.15	0.14	2.06	
		1.09		3.87	0.13	3.20	
		1.50		15.40	0.37	2.37	
		1.08		4.86	0.16	4.57	
		0.38		4.15	0.15	2.09	
		1.12		3.87	0.13	1.18	
		1.46		15.40	0.38	3.18	
		1.31		15.40	0.47	6.18	
		2.44		10.07	0.23	0.90	
		2.03		10.07	0.22	1.66	
Lark River (England)	Shallow	1.74		10.94	0.28	0.78	
		1.47		10.94	0.37	2.12	
		1.82		36.20	0.50	1.41	
		2.41		36.20	0.43	0.31	

TABLE C-1 (continued)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Derwent River (England)		0.72		21.60	1.37	31.80	
		0.89		21.60	1.19	24.53	
		0.85		21.60	1.07	34.57	
Black Beck River (England)	Shallow	0.40		2.70	0.44	25.59	
		0.40		2.70	0.56	28.34	
		0.39		2.70	0.63	22.80	
		0.60		17.70	1.83	49.17	
		0.69		17.70	1.81	30.77	
		1.00		17.70	1.54	18.46	
St. Sunday's Beck (Eng.)	Shallow	0.82		19.10	1.07	21.05	
		0.78		19.10	1.27	16.06	
Yewdale Beck (England)	Shallow	0.64		5.10	0.46	12.04	
		0.48		5.10	0.60	30.32	
		0.72		17.30	1.16	18.90	
		0.66		17.30	1.31	20.25	
		0.67		17.30	1.30	17.09	
		0.69		17.30	1.25	19.16	
Elk River (Penna.)	Shallow	0.9			0.97	5.84	

TABLE C-1 (continued)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Mohawk River	Shallow	3	143.			.07-4.0	.23
Mohawk River (New York)	Medium	15	3,800.	800.	.21		.40
North Branch Susquehanna	Medium	4	1,700.	1,000.	0.60	1.5	0.35
New River (Virginia)	Medium	5	1,720.	1,200.	0.70	1.04	2.5 0.5
Wabash (Indiana)	Medium	5-7		1,000-5,000			.40
Clinch River (T.V.)	Medium	3.27		3,300.	3.07	2.27	
		5.09		4,500	3.69	1.44	
		4.42		3,190	3.10	.98	
		6.14		5,890	2.68	.50	
		5.65		5,910	2.78	.74	
		7.17		5,930	2.64	1.13	
Holston (T.V.)	Medium	11.41		10,385	2.92	.28	
		2.12		3,230	2.47	3.36	
		2.93		6,400	3.44	2.79	
		4.54		14,085	4.65	1.57	
		9.50		10,440	3.94	.46	
		6.29		6,540	2.51	.39	

TABLE C-1 (continued)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Holston River (T.V.)	Medium	7.52		10,500	3.15	.27	
		7.07		10,500	3.30	.55	
		5.44		5,590	3.11	.54	
		8.06		11,930	4.28	.60	
		3.98		952	2.73	1.25	
Fr. Broad (T.V.)	Medium	9.38		12,010	2.41	.27	
		10.19		17,120	3.06	.23	
		3.29		44,105	2.40	1.88	
		4.74		8,775	3.46	.84	
		5.72		12,455	4.02	.88	
		6.98		17,270	52	.91	
		4.29		4,150	85	1.00	
		6.01		8,775	.75	.55	
		7.16		12,455	.23	.98	
		9.49		17,270	3.71	.25	
Wautaga River (T.V.)	Medium	3.42		3,112	5.0	43.	5.6
Hiwassee River (T.V.)	Medium	3.02		1,145	3.05	11.	1.7
		2.83		1,145	3.91	21.	3.2
Ohio River	Deep	32	43,000	6,000	.14		.06

TABLE C-1 (continued)

River Name	Category	Depth (ft.)	Area (ft^2)	Flow (cfs)	Velocity (fps)	k_a @20°C (1/day)	k_L @20°C (1/day)
Upper Hudson (Troy, N.Y.-Saugerties)	Deep	17.5	6,000	3,000	0.5	.34	.125
		21.0	6,750	4,500	1.5	.34	.165
Lower Sacramento River	Deep	15-20	8,000	10,000	1.5	.28	.40
						.15	
						.24	
Upper James River (Va.)	Deep	15.5	11,500	1,800	0.16	.15	.48
			14,500	2,600	0.18	.14	.30
			14,500	9,000	0.63	.12	.31
			14,000	7,500	0.53	.12	.42
			14,500	4,500	0.31	.22	.39
			13,500	3,800	0.28	.24	.38
			15,000	1,350	0.13	.22	.43
Illinois River	Deep	10-12		8,000			.07
		9.2			1.37	.225	
		9.0			1.57	.269	
		8.9			1.63	.224	

TABLE C-2

DEOXYGENATION RATE CONSTANTS (FROM BANSAL, 1975)

				k_L rates base e/day	
Discharge cfs	X-section area sq ft.	Top Width ft.	Temp °C	Observed	Estimated (From Fig. C-1)
Kansas River at Bonner Springs, Kansas					
15,200	4,300	770	25	.02	.258
2,160	1,200	505	28	.12	.249
2,090	1,170	500	25	.12	.242
2,440	1,300	525	24	.24	.241
1,300	850	450	9	.02	.204
828	550	415	5	.16	.190
632	425	405	9	.26	.195
1,080	710	432	14	.17	.213
Kansas River at Lecompton, Kansas					
1,750	750	725	27	.19	.232
1,360	590	660	32	.15	.239
2,060	880	774	28	.35	.236
2,300	1,000	757	10	.30	.201
1,040	450	592	6	.47	.184
793	350	538	0	.23	.169
1,170	500	620	16	.05	.206
Kansas River at Topeka, Kansas					
3,040	1,450	468	22	.08	.241
1,460	700	437	31	.07	.248
1,800	865	447	27	.1	.243
2,690	1,285	466	18	.37	.230
1,900	910	450	7	.14	.200
764	365	405	7	.06	.189
631	310	368	11	.23	.196
608	290	364	15	.10	.204

TABLE C-2 (continued)

Discharge cfs	X-section area sq ft.	Top Width ft.	Temp °C	k_L rates base e/day Observed	k_L rates base e/day Estimated (From Fig. C-1)
Republic River below Milford, Kansas					
258	184	196	24	.18	.224
657	412	251	28	.19	.242
609	392	249	24	.07	.283
201	140	166	14	.25	.203
15	10	6[illegible]	1	.14	.153
36	26	77	0	.23	.161
249	177	192	16	.29	.208
Smoky Hill River at Enterprise, Kansas					
215	122	119	27	.09	.232
100	57	69	32	.26	.238
373	211	131	24	.16	.234
146	83	91	6	.32	.193
113	65	75	0	.14	.173
210	120	118	15	.17	.207
157	88	97	14	.24	.204
Smoky Hill River at New Cambridge, Kansas					
185	87	86	27	.09	.232
67	35	79	31	.19	.225
734	252	88	29	.27	.255
Solomon River at Niles, Kansas					
61	65	53	28	.21	.237
35	40	49	30	.19	.234
117	125	61	21	.06	.231

TABLE C-2 (continued)

				k_L rates base e/day	
Discharge cfs	X-section area sq ft.	Top Width ft.	Temp. °C	Observed	Estimated (From Fig. C-1)
Kansas River at Wamego, Kansas					
890	390	413	27	.23	.231
1,540	670	468	26	.13	.236
2,530	1,080	540	27	.30	.244
1,470	730	462	15	.26	.214
680	300	395	0	.28	.171
535	225	381	2	.11	.172
483	190	375	7	.06	.181
Big Blue River at Tuttle Creek, Kansas					
1,060	1,050	194	22	.21	.251
162	70	76	24	.14	.224
90	42	62	27	.23	.225
810	490	191	23	.28	.240
961	1,000	194	8	.6	.217
232	108	92	1	.37	.179
50	30	52	6	.15	.181
50	30	52	13	.2	.195
Kansas River at Manhattan (Fort Riley), Kansas					
1,250	4,250	533	26	.26	.268
559	1,750	493	32	.15	.265
1,200	4,050	530	26	.10	.267
511	367	247	25	.09	.234

TABLE C-2 (continued)

				k_L rates base e/day	
Discharge cfs	X-section area sq ft.	Top Width ft.	Temp. ^oC	Observed	Estimated (From Fig. C-1)
Solomon River at Glen Elder, Kansas					
44	38	49	28	.20	.229
47	40	49	28	.23	.23
79	58	53	24	.10	.227
30	30	33	7	.35	.21
48	41	49	0	.34	.172
33	31	36	0	.37	.173
30	30	33	5	.35	.185
Saline River at Tescott, Kansas					
8.3	14	19.4	2.7	.37	.226
5.8	10	17.8	28	.25	.224
132	75	30	21	.26	.235
Smoky Hill River at Mentor, Kansas					
138	88	83	24	.10	.226
35	20	81.5	26	.15	.207
675	288	92.5	26	.42	.25
Smoky Hill River at Langley, Kansas					
77	60	57	23	.42	.224
147	85	67	27	.51	.236
493	210	90	24	.14	.240
249	122	75	23	.14	.232
14	15	20	7	.20	.186
21	21	23	1	.28	.176
18	19	22	6	.29	.186
81	60	58	11	.33	.199

TABLE C-2 (continued)

	Discharge cfs	X-section area sq ft.	Top Width ft.	Temp. °C	k_L rates base e/day Observed	k_L rates base e/day Estimated (From Fig. C-1)
Grand River, Michigan						
	295	320	168.4	20	.59	.228
Clinton River, Michigan						
	33	44.6	28.22	20	3.37	.225
Truckee River, Nevada						
	180	150	89.8	20	.36	.226
	195	150	89.8	20	.36	.226
	271	150	89.8	20	.96	.226
Flint River, Michigan						
	134	210	100		.56	.230
	174	200	76.9	20	.63	.233
	174	400	153.8	20	.69	.233
	204	296	170.6	20	.69	.226
	204	400	210.5	20	.69	.228
Jackson River, Virginia						
	100	365	122	20	1.25	.236
North Branch Potomac River (Maryland, West Virginia)						
	100	100	50	20	.4	.229
North Branch Susquehanna						
	1,000	1,700	425	20	.35	.241

TABLE C-2 (continued)

				k_L rates base e/day	
Discharge cfs	X-section area sq ft.	Top Width ft.	Temp. ^{o}C	Observed	Estimated (From Fig. C-1)
New River, Virginia					
1,200	1,720	344	20	.5	.245
Upper Hudson, Troy, New York					
3,000	6,000	343	20	.125	.269
4,500	6,750	321	20	.165	.273
Lower Sacramento River					
10,000	8,000	457	20	.4	.269
Upper James River, Virginia					
1,800	8,000	742	20	.48	.267
2,600	11,500	935.5	20	.30	.267
9,000	14,500	935.5	20	.31	.267
7,500	14,000	903.2	20	.41	.267
4,500	14,500	935.2	20	.39	.267
3,800	13,500	871	20	.38	.267
1,350	15,000	967.7	20	.43	.267
Cooper River, South Carolina					
10,000	40,000	1,000	20	.3	.286
Savannah River, Georgia and South Carolina					
7,000	10,000	1,000	20	.3	.258
6,800	40,000	1,428.6	20	.3	.279

TABLE C-2 (continued)

	Discharge cfs	X-section area sq. ft.	Top Width ft.	Temp. °C	k_L rates base e/day Observed	k_L rates base e/day Estimated (From Fig. C-1)
South New Jersey						
	23	2,500	208.3	20	.2	.262
Compton Creek, New Jersey						
	10	1,000	69	20	.23	.265
	10	790	75	20	.23	.259

TABLE C-3

ALLUVIAL CHANNEL AND SEDIMENT DATA (FROM SCHUMM, 1960)

Location	Median grain size, D_{50} (mm)	Silt-clay in bank (percent)	Silt-clay in channel (percent)	Weighted mean silt-clay M (percent)	Width (feet)	Depth (feet)	Width depth ratio (F)	Gradient (S)	Mean annual flood (cfs)	Mean annual discharge (cfs)	Drainage area (sq mi)
Smoky Hill-Kansas Rivers system											
Willow Creek near Cheyenne Wells,Colo-	1.10	72	3	16	15	1.7	8.8	------	------	------	------
Smoky Hill River near Arapahoe,Colo---	.85	49	3	6.1	65	2.3	28	0.003	------	30(est)	------
Smoky Hill River near Sharon Springs, Kans-------------------------------	.41	25	4	4.5	200	2.5	80	------	------	------	------
Smoky Hill River at Russell Springs, Kans-------------------------------	1.30	21	2	2.4	263	3.0	88	------	------	------	------
Smoky Hill River at Gove,Kans---------	.80	63	3	4.3	226	2.5	90	------	------	------	------
Smoky Hill River near Arnold,Kans-----	.93	30	2	2.4	345	2.5	138	------	5,800	65.2	5,220
Smoky Hill River near Russell,Kans----	.81	76	1	5.3	115	3.5	33	.00066	8,000	215	6,965
Smoky Hill River at Dorrence,Kans-----	1.30	69	.5	4.4	130	4.0	33	.0007	------	------	------
Smoky Hill River near Kanopolis (Longley),Kans-----------------------	.63	96	4	14	92	5.5	17	.0005	9,200	314	7,857
Smoky Hill River near Bridgeport (Lindsborg),Kans--------------------	.40	85	3	13	69	5.0	14	------	6,750	340	8,110
Smoky Hill River at Abilene,Kans------	.023	97	87	89	125	18	7	------	11,500	1,254	18,830
Smoky Hill River near Junction City, Kans-------------------------------	1.20	90	.5	6	153	5.0	31	.0004	13,000	1,454	19,900
Kansas River at Wamego,Kans-----------	.70	93	1	3.8	636	10	64	.0008	39,000	4,398	55,240
Kansas River near Topeka,Kans---------	.75	57	.5	3	800	18	44	.0005	48,000	5,155	56,710
Republican River System											
Arikaree River near Arikaree,Colo-----	1.10	82	3	4.7	206	2.2	94	------	------	------	------
Arikaree River at Haigler,Nebr--------	.25	65	3	8	68	3.0	23	0.002	3,500	19.6	1,460
Republican River near Stratton,Nebr---	.38	31	3	3.4	400	3.0	133	------	------	------	------
South Fork Republican River near Benkleman,Nebr.------------------------	.48	44	1.5	3.4	100	2.3	43	.002	4,500	56.8	2,580
Republican River near Benkleman,Nebr--	.25	23	6	6.7	123	2.5	49	.003	2,175	105	4,770
Republican River near McCook,Nebr-----	.52	88	.5	4.4	115	2.7	43	.009	------	------	5,760
Republican River near Bostwick(Hardy), Nebr-------------------------------	.63	29	1	2.8	154	5.0	31	.0008	12,000	843	22,400
Republican River at Concordia,Kans----	.70	34	.2	1.4	250	5.0	50	.0007	13,000	------	23,540
Republican River at Junction City,Kans	.60	59	1	3.4	300	6.5	46	.0007	15,000	1,000	24,900
Powder River System											
South Fork Powder River near Kaycee, Wyo-------------------------------	0.63	71	9	11.3	119	2.3	52	0.004	3,900	35	1,150
Middle Fork Powder River above Kaycee, Wyo-------------------------------	22.0	60	14	20	35	2.5	14	.005	574	58	450
Middle Fork Powder River near Kaycee, Wyo-------------------------------	.40	69	15	23	47	4.4	11	.0015	1,630	133	980
Powder River below Arvada,Wyo-------	.21	70	4	6.5	175	3.5	50	.0011	------	------	------
Powder River near Locate,Mont-------	.42	58	13	15	234	4.5	52	------	9,400	639	------
Crazy Woman Creek near Arvada,Wyo---	.50	75	2	17	33	4.4	7.5	------	1,150	40	956
Little Powder River at Broadus,Mont-	4.10	82	5.5	22	40	5.5	7.3	------	1,280	39	------
Bighorn River near Kane,Wyo---------	.16	35	20	21	220	8.5	26	------	16,100	2,888	15,900
Badwater Creek near Lysite,Wyo------	.43	47	3	6.7	50	2.3	22	.0037	------	------	------
Badwater Creek at Lysite,Wyo--------	.24	58	5	7.3	109	2.5	44	.0037	------	------	------
Owl Creek near Thermonolis,Wyo------	.21	69	2	14	35	3.9	9.0	.0015	585	34	484
Cottonwood Creek at Winchester,Wyo--	1.0	15	8	8.4	133	3.5	38	------	------	------	------
Gooseberry Creek at Pulliam,Wyo-----	8.0	45	2.5	5.7	59	2.4	25	.006	311	10	371
Graybull River near Basin,Wyo-------	.50	72	7	9.9	134	3.1	43	.0015	3,140	178	1,130
Bates Creek near Alcova,Wyo---------	.90	63	14	18	69	2.8	25	.0035	500	16	377

TABLE C-3 (continued)

Location	Median grain size, D_{50} (mm)	Silt-clay in bank (percent)	Silt-clay in channel (percent)	Weighted mean silt-clay M (percent)	Width (feet)	Depth (feet)	Width depth ratio (F)	Gradient (S)	Mean annual flood (cfs)	Mean annual discharge (cfs)	Drainage area (sq mi)
Sage Creek, S.Dak.:											
(2)	0.06	93	55	73	16	7	2.3	0.0055	-----	-----	1.7
(3)	.06	93	68	79	20	7	2.9	.0045	-----	-----	3.4
(4)	.12	96	40	54	31	5	6.2	.0045	-----	-----	9.5
Sand Creek, Nebr:											
(4)	.72	70	14	23	75	7	10.7	.0015	-----	-----	17.9
(5)	.73	60	15	22	65	7	9.3	.003	-----	-----	22.2
(6)	.35	65	10	20	36	4	9.0	.001	-----	-----	22.5
Arroyo Calabasas, N. Mex.:											
(A)	.84	18	3	4.1	79	3	26.3	.013	-----	-----	3.8
(6)	.50	26	3	4.8	92	4	23.0	.009	-----	-----	24.2
(7)	.75	16	5	5.8	100	4	25.0	.011	-----	-----	25.8
Bayou Gulch, Colo.:											
(3)	.58	13	4	4.4	130	3	43	.010	-----	-----	19.7
(6)	.55	6	4	4.1	128	1.5	85	.016	-----	-----	22.9
Medano Creek, Colo.:											
(1)	.24	.5	1	1	340	2	170	.017	-----	-----	25.8
(2)	.24	.5	1	1	800	3	267	.019	-----	-----	26.1
(3)	.24	.5	.5	.5	820	2.5	328	.016	-----	-----	28.8
Saline River at Russell, Kans.	3.57	93	5.7	11	93	3	31	-----	4,300	88.3	1,502
Paradise Creek near Paradise, Kans.	.50	74	8	30	32	7.8	4.1	.001	1,300	11.1	212
North Fork Solomon River near Downs Kans.	.80	89	1.2	16	82	8.6	9.6	.0006	8,000	151	2,390
Solomon River at Bennington(Niles),Kans-	.41	90	4	11	112	5	22	-----	7,000	558	6,770
Prairie Dog Creek at Norton, Kans.	.90	82	1.5	19	45	6.2	7.2	.0005	2,600	33.2	721
Sappa Creek at Stamford, Nebr.	.60	97	2	23	43	6.0	7.2	.0013	1,800	111	3,840
Sappa Creek at Beaver City, Nebr.	.70	96	17	43	26	6.3	4.1	.003	1,350	39.1	1,500
Beaver Creek at Beaver City,Nebr.	.70	95	2	19	40	4.5	8.9	.001	1,000	28.8	2,060
Beaver Creek at Ludell, Kans.	1.10	95	2.5	35	26	8.0	3.5	.001	450	12.5	1,460
Frenchman Creek at Hamlet, Nebr.	.27	93	8.7	31	36	6.5	5.5	.0013	850	101	1,480
Blackwood Creek at Culbertson, Nebr.	.02	91	75	81	27	8.4	3.2	.0021	690	5.8	290
Red Willow Creek near Red Willow,Nebr.	.11	91	30	45	45	7.1	6.3	.001	2,220	43.1	400
South Loup River near Cumro, Nebr.	.25	80	9.4	16	143	7.3	19.6	.003	2,080	165	1,340
Niobrara River near Colclesser,Nebr.	.33	47	2	3.3	224	3.4	65.9	.003	-----	-----	2,000
White River at Chadron,Nebr.	.15	86	32.5	56	25	10.0	2.5	-----	880	20.4	676
White River at Interior,S.Dak.	.50	89	2	5.3	293	5.8	50.6	.002	10,900	302	------
Cheyenne River at Edgemont,S.Dak.	.75	56	.6	3	221	5.0	44.2	.0025	3,660	113	7,143

APPENDIX D

IMPOUNDMENT THERMAL PROFILES

Thermal profile plots are provided for a variety of impoundment sizes and geographic locations throughout the United States. The locations are arranged in alphabetical order. Within each location set, the plots are ordered by depth and hydraulic residence time. An index to the plots is provided below, and the modeling approach is described in Appendix F.

Page

Atlanta, Georgia

20-ft Initial Maximum Depth D-4
40-ft Initial Maximum Depth D-14
75-ft Initial Maximum Depth D-24
100-ft Initial Maximum Depth D-34
200-ft Initial Maximum Depth D-44

Billings, Montana

20-ft Initial Maximum Depth D-54
40-ft Initial Maximum Depth D-64
75-ft Initial Maximum Depth D-74
100-ft Initial Maximum Depth D-84
200-ft Initial Maximum Depth D-94

Burlington, Vermont

20-ft Initial Maximum Depth D-104
40-ft Initial Maximum Depth D-114
75-ft Initial Maximum Depth D-124
100-ft Initial Maximum Depth D-134
200-ft Initial Maximum Depth D-144

Flagstaff, Arizona

20-ft Initial Maximum Depth D-154
40-ft Initial Maximum Depth D-164
75-ft Initial Maximum Depth D-174
100-ft Initial Maximum Depth D-184
200-ft Initial Maximum Depth D-194

Page

Fresno, California

20-ft Initial Maximum Depth D-204
40-ft Initial Maximum Depth D-214
75-ft Initial Maximum Depth D-224
100-ft Initial Maximum Depth D-234
200-ft Initial Maximum Depth D-244

Minneapolis, Minnesota

20-ft Initial Maximum Depth D-254
40-ft Initial Maximum Depth D-264
75-ft Initial Maximum Depth D-274
100-ft Initial Maximum Depth D-284
200-ft Initial Maximum Depth D-294

Salt Lake City, Utah

20-ft Initial Maximum Depth D-304
40-ft Initial Maximum Depth D-314
75-ft Initial Maximum Depth D-324
100-ft Initial Maximum Depth D-334
200-ft Initial Maximum Depth D-344

San Antonio, Texas

20-ft Initial Maximum Depth D-354
40-ft Initial Maximum Depth D-364
75-ft Initial Maximum Depth D-374
100-ft Initial Maximum Depth D-384
200-ft Initial Maximum Depth D-394

Washington, D.C.

20-ft Initial Maximum Depth D-404
40-ft Initial Maximum Depth D-414
75-ft Initial Maximum Depth D-424
100-ft Initial Maximum Depth D-434
200-ft Initial Maximum Depth D-444

Wichita, Kansas

20-ft Initial Maximum Depth D-454
40-ft Initial Maximum Depth D-464
75-ft Initial Maximum Depth D-474
100-ft Initial Maximum Depth D-484
200-ft Initial Maximum Depth D-494

APPENDIX E

MODELING THERMAL STRATIFICATION IN IMPOUNDMENTS

Figure E-1 Comparison of Computed and Observed Temperature Profiles in Kezar Lake

Figure E-2 Comparison of Computed and Observed Temperature Profiles in El Capitan Reservoir

Figure E-3 Log of Eddy Conductivity Versus Log Stability--Hungry Horse Data

IMPOUNDMENT THERMAL PROFILE MODEL: BACKGROUND

The model used for computation of impoundment temperature profiles is based on the Lake Ecologic Model originally developed by Chen and Orlob (1975). The model was modified for this application to compute temperature alone. The purpose of the model application was to simulate the effects of mixing, impoundment physical characteristics, hydraulic residence time, and climate on the vertical profiles of temperature.

Physical Representation

Each configuration simulated was idealized as a number of horizontally mixed layers. Natural vertical mixing is computed by the use of dispersion coefficients in the vertical mass transport equation. Values of the dispersion coefficients for different size lakes were estimated from previous studies (Water Resources Engineers, Inc., 1969).

Temperature

Temperatures were computed as a function of depth according to Equation (E-1).

$$\bar{v} \frac{\partial T}{\partial t} = \frac{1}{c\rho} \frac{\partial}{\partial z} (A_z D_z \frac{\partial T}{\partial z}) - \frac{\partial}{\partial z} (QT) + \frac{A_s}{c\rho} (\mu - \lambda T) + \frac{\Theta}{c\rho} - T \frac{\partial \bar{v}}{\partial t} \qquad \text{(E-1)}$$

where T = the local water temperature

c = specific heat

ρ = fluid density

A_z = cross-sectional area at the fluid element boundary

t = time

z = vertical distance

D_z = the eddy diffusion coefficient in the vertical direction

Q = advection across the fluid element boundaries

A_s = cross-sectional area of the surface fluid element

μ, λ = coefficients describing heat transfer across air-water interface

Θ = sum of all external additions of heat to fluid volume of fluid element

$\bar{v}$ = element volume

Application/Verification

The model has recently been used in a lake aeration study (Lorenzen and Fast, 1976). In that study, the model was applied to Kezar Lake in New Hampshire and El Capitan Reservoir in California to verify that artificial mixing could be adequately simulated.

Computed temperature profiles were compared to observed values as shown in Figures E-1 and E-2. The model performance was judged to be good for the intended purpose of providing guidance for further study.

PREPARATION OF THERMAL PROFILES

The thermal profiles in Appendix D of this report were prepared by inputting the selected climatological conditions, inflow rate, impoundment physical conditions, and wind. Of these, only wind warrants special discussion here. The remaining model parameters are discussed in the text of Chapter 5.

Wind-Induced Mixing and the Eddy Diffusion Coefficient

Figure E-3 is a plot of the eddy conductivity coefficient versus stability. It was used to obtain coefficients for wind mixing for the

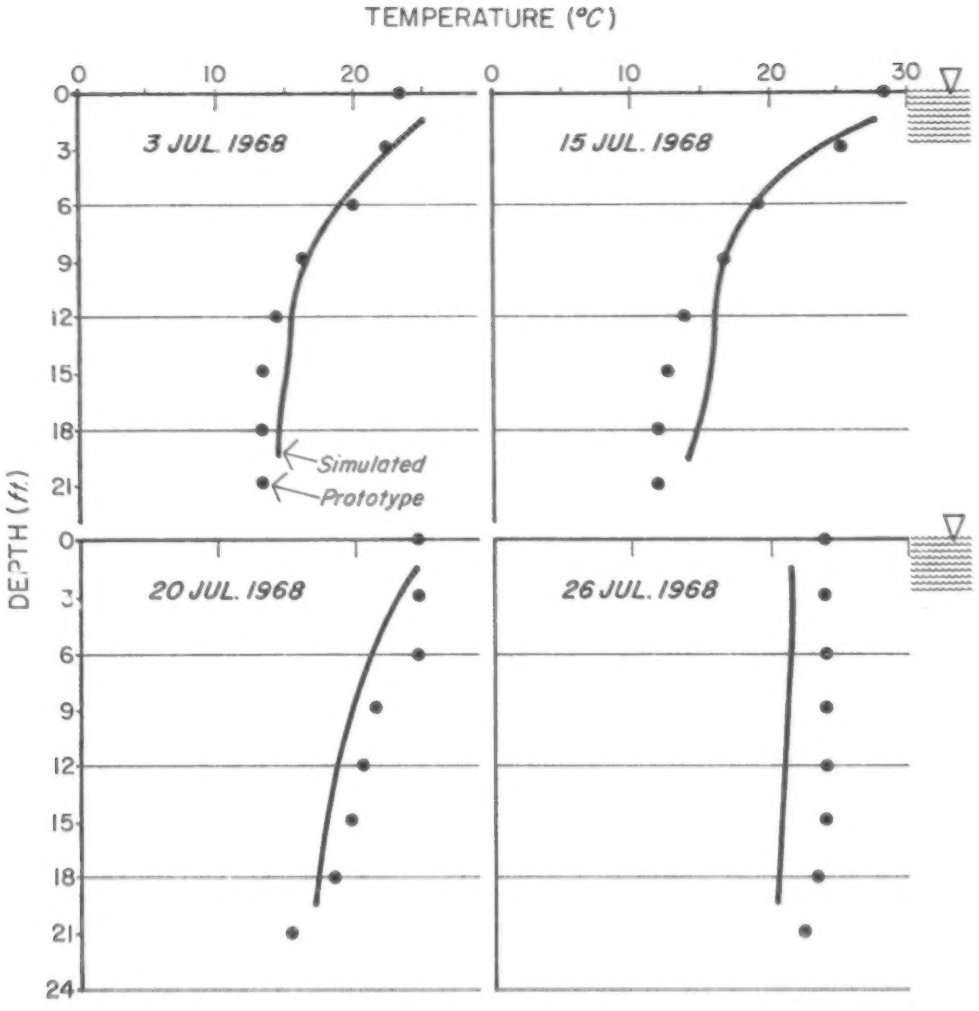

FIGURE E-1 COMPARISON OF COMPUTED AND OBSERVED TEMPERATURE PROFILES IN KEZAR LAKE

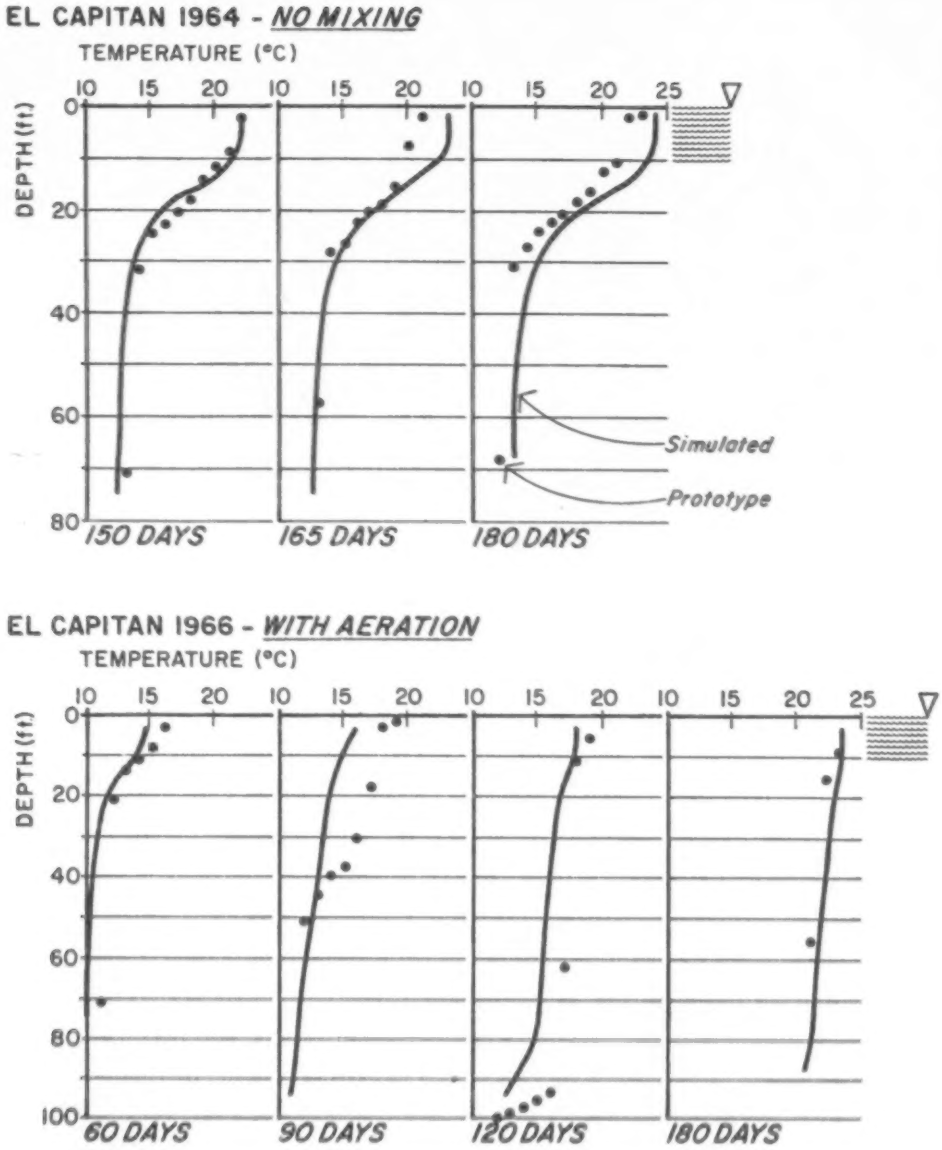

Figure E-2 Comparison of Computed and Observed Temperature Profiles in El Capitan Reservoir

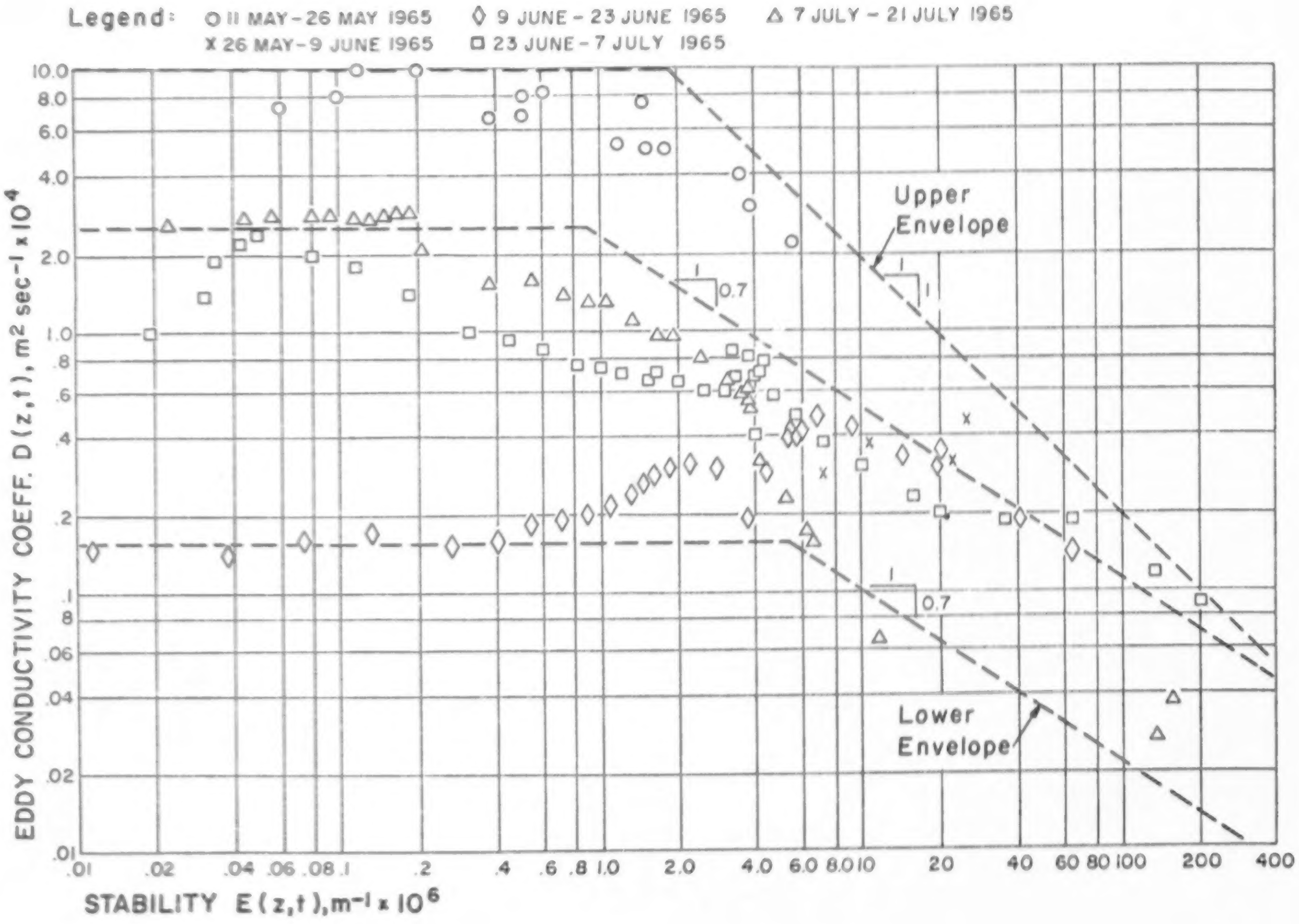

FIGURE E-3 PLOT OF THE EDDY CONDUCTIVITY COEFFICIENT, D(Z,T) VERSUS STABILITY, E(Z,T) FOR HUNGRY HORSE RESERVOIR DATA (AFTER WATER RESOURCES, INC., 1969) model runs. The upper envelope represents high wind mixing conditions and the lower envelope represents low wind mixing conditions. Note that the plot in Figure E-3 was developed for this model, and the model was then verified with data from Hungry Horse Reservoir, which is located on the South Fork of the Flathead River in northwestern Montana. Accordingly, the extremes of wind mixing and the effects on impoundment stability are as found for Hungry Horse Reservoir. The coefficients should be applicable elsewhere, however, because the eddy diffusion coefficient is relatively insensitive to climate and location.

The significance of the eddy conductivity coefficient and its implications for wind mixing may be understood by examining an equation describing transport within the system. Mixing implies the transfer of materials or properties within a system from points of high concentration to points of low concentration, and vice versa. For a system which is undergoing forced convection, it has been observed that the time rate of transport, F, of a property, S, through the system is proportional (other things being equal) to the rate of change of concentration of this property with distance, z. In equation form, this rule is expressed as:

$$F = - D \frac{\partial S}{\partial z} \qquad \text{(E-2)}$$

where D is the coefficient of proportionality. The mixing process as defined by Equation (E-2) is variously called "effective diffusion," "eddy diffusion," or the "diffusion analogy" because it is identical in form to the equation describing the process of molecular diffusion. The difference between the two processes, however, is that for molecular diffusion, D is constant, while for turbulent transfer, D is a function of the dynamic character, or the turbulence level, of the system. In general, D is a temporal and spatial variable, and thus will be referred to here as D(z,t). Equation (E-2) rewritten for heat flow over the reservoir vertical axis is

$$H = -\rho c D(z,t) \frac{\partial T}{\partial z} \tag{E-3}$$

where H = heat flux, $HL^{-2}T^{-1}$

ρ = density of water, ML^{-3}

c = heat capacity of water, $HM^{-1}D^{-1}$

$D(z,t)$ = coefficient of eddy conductivity, $L^{2}T^{-1}$

T = temperature, D

z = elevation in the reservoir, L

t = time T

From Equation (E-3), therefore, it may be seen that the rate of heat flux (H), which describes the rate of energy transfer vertically in an impoundment, is a function of the temperature gradient over depth ($\frac{\partial T}{\partial z}$) and the degree of turbulence (induced by wind and other factors) and is characterized by the eddy diffusion coefficient D(z,t) in the equation. It is this coefficient, D(z,t) which is plotted on the ordinate (stability is on the abscissa) in Figure E-3.

Surface Heat Flux

The simulation of temperature involves the following steps:

1. The net heat transfer at the air-water interface is evaluated for all surface nodes as a function of the meteorological variables and nodal temperatures.

2. The heat input due to shortwave solar radiation is distributed with depth according to the light transmissibility characteristics of the water (which are a function of the suspended particulates).

3. Heat is distributed within the water body by hydrodynamic transport (advection and dispersion) in the same manner as conservative dissolved constituents.

The net rate of heat transfer across the air-water interface is computed according to the following heat budget equation:

$$H = q_{sn} + q_{at} - q_w - q_e \pm q_c \qquad \text{(E-4)}$$

where

H = Net rate of heat transfer (Kcal/m²/sec)

q_{sn} = net shortwave solar radiation across the air-water interface, including losses by absorption and scattering in the atmosphere, and reflection at the water surface (Kcal/m²/sec)

q_{at} = atmospheric long wave radiation across the air-water interface (Kcal/m²/sec)

q_w = long wave back radiation from the water surface to the atmosphere (Kcal/m²/sec)

q_e = evaporative heat loss (Kcal/m²/sec)

q_c = convective heat exchange between the water surface and the atmosphere (Kcal/m²/sec)

The heat transfer terms for long wave back radiation, evaporative heat loss, and convective heat exchange depend on the water temperature in the surface nodes (λ values), while the solar radiation and atmospheric long wave radiation (μ values) are independent of water temperature. Algorithms for the various terms of Equation E-2 are used for separate computation and then summed as shown in Equation E-1.

NOTE:

For a more detailed description of the model, its applicability, and the eddy diffusion coefficient, the reader is referred to a report entitled "Mathematical Models for the Prediction of Thermal Energy Changes in Impoundments." (See the list of references at the end of this Appendix.)

REFERENCES FOR APPENDIX E

Chen, C.W., and Orlob, G.T., 1975. Ecologic simulation for aquatic environments in systems analysis and simulation in ecology. Academic Press, N.Y., San Francisco, and London. III:475-588.

Lorenzen, M.W., and Fast, A., 1976. A Guide to Aeration/Circulation Techniques for Lake Management: For U.S. Environmental Protection Agency Corvallis, Oregon.

Water Resources Engineers, Inc., 1969. Mathematical Models for the Prediction of Thermal Energy Changes in Impoundments. Water Quality Office, Environmental Protection Agency.

APPENDIX F

RESERVOIR SEDIMENT DEPOSITION SURVEYS

The material in this appendix consists of a reproduction of a bulletin compiled by F. E. Dendy and W. A. Champion, which provides data on rates of sedimentation in U. S. reservoirs.

INTRODUCTION

Data from known reliable reservoir sedimentation surveys made in the United States through 1970 are summarized in this bulletin. Additional data from surveys made after 1970 are included for a few reservoirs.

This bulletin supersedes USDA Miscellaneous Publication No. 1143, which was published in May, 1969.[1/] All reservoir surveys reported in Miscellaneous Publication No. 1143 have been repeated in this bulletin. In addition, it includes surveys made before 1965, but not previously reported, and new data on reservoirs surveyed or resurveyed since 1965. The reservoirs are located in all of the 48 conterminous United States, except Florida, and in Puerto Rico. In addition to data on storage reservoirs and ponds, some information on debris basins is included.

A supplement to this bulletin, from which the data were extracted and summarized, contains detailed information about each of the reservoirs

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[1/] Dendy, F.E. and Champion, W.A., Compilers. Summary of Reservoir Sediment Deposition Surveys Made in the United States Through 1965. U.S. Department of Agriculture Miscellaneous Publication No. 1143, 64 pp., May, 1969. (Cooperative report with the Sedimentation Committee. Water Resources Council).

listed in the summary table. The method used in presenting this information is given on pages **F-2, F-3, F-4 and F-5**. The supplement has not been distributed with this bulletin because of its bulk and because the detailed information is not of general interest. Copies are available in the offices of the agencies represented on the Sedimentation Committee of the Water Resources Council. Reprints of data sheets for specific reservoirs may be obtained on request from the Director, USDA Sedimentation Laboratory, U.S. Department of Agriculture, Oxford, Miss. 38655. Requests for information not contained in this bulletin or in the supplement should be directed to the agency supplying the data.

The accuracy of the survey data varies greatly. Surveys range from reconnaissance measurements of sediment depth at a few locations to detailed surveys based on closely spaced cross sections or contours. No attempt has been made to classify the surveys according to degree of accuracy.

Information in this bulletin and in the supplement should prove useful to engineers and watershed planning specialists in private and public practice who are concerned with problems of reservoir sedimentation. Engineers, engineering firms and local government agencies who have data on similar reservoir surveys are invited to make this information available to the Sedimentation Committee, WRC, for inclusion in supplements to this publication.

EXPLANATION OF THE SUMMARY TABLE

Data in the summary table of this bulletin were obtained from the reservoir sedimentation survey data sheets contained in the supplement. Dashes in columns of the table signify that data were unavailable or that the column is not applicable for the reservoir.

Reservoirs are grouped according to the 79 drainage areas into which the United States has been divided as shown in the publication, "River Basin Maps Showing Hydrologic Stations," compiled under the auspices of the Subcommittee on Hydrology, Federal Inter-Agency River Basin

Committee.[2] An index map of these drainage areas is shown on page F-78. The drainage areas in which the reservoirs are located are shown as subheadings in the summary table. The first of the two numbers identifying a reservoir indicates the drainage basin in which it is located. The second number denotes the particular reservoir in the drainage area and is based upon the order in which the data were prepared. These numbers are the same as those identifying the corresponding survey data sheets in the supplement. When a survey data sheet is revised or when another sheet is prepared with information for additional surveys, the identification number is modified by the addition of letters beginning with a; for example, 13-2, 13-2a, and 13-2b.

Total drainage area includes the reservoir area and the area lying above all upstream dams but generally excludes noncontributing drainage areas lying within the watershed boundary. Where available, the drainage area figure published by the U.S. Geological Survey in Water-Supply Papers is usually used. The net drainage area is the sediment-contributing area and generally excludes the reservoir area and the drainage areas above upstream reservoirs, or other structures which are effective sediment traps.

The first date shown usually corresponds to the beginning of storage when sediment deposition began. However, for some reservoirs the first date represents the date of the contour or range survey made after the reservoir had been in operation for some time.

For most reservoirs, the storage capacity given is the total storage below the level of the crest of an ungated spillway or the top of gates (less gate-height freeboard, if any) of gated spillways. Where capacity values below the spillway crest elevation are given, footnotes are used to explain.

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[2] U.S. Inter-Agency Committee on Water Resources, Subcommittee on Hydrology. River Basin Maps Showing Hydrologic Stations. U.S. Dept. Com., Weather Bur., Notes on Hydrol. Activ. Bul. 11, 79 pp., 1961.

The capacity-average annual inflow ratio (C/I ratio) was derived from the reservoir storage capacity and the average annual inflow. Normally the average annual inflow for the entire period of record was used to compute the C/I ratios. This time period may or may not correspond to the period for which sediment accumulation was given. Generally, the C/I ratio was not given if upstream structures controlled 25 percent or more of the drainage area.

The specific weight of deposited sediment is an average or weighted value for the reservoir, determined generally from samples of deposits. In view of the variations with depth and location within the reservoir, specific weight is generally an approximation for the reservoir. The entry is marked by an asterisk where the specific weight is assumed or is calculated from field data or the size-frequency grading of the deposits.

The average annual rate of sediment accumulation (acre-feet and tons per square mile of net drainage area) pertains to sediment deposited in the reservoir below the full pool elevation. Sediment deposited in deltas above full pool level or sediment discharged from the reservoir is not included unless explained by footnote. For reservoirs with more than one survey and where the latest survey indicated an increase in the specific weight of deposited sediment, the annual sediment accumulation rate in tons per square mile was not always computed in the same manner. For some reservoirs, compaction of earlier sediment was considered and in others it was not. All of the deposited sediment was assumed to have been transported into the reservoir by water.

The agency supplying data is shown in the last column of the table. This agency either has the basic data available or has access to it through cooperative arrangements. The symbols used in this column apply to the following agencies:

ARS - Agricultural Research Service
BR - Bureau of Reclamation
CE - Corps of Engineers
FS - Forest Service
GS - Geological Survey
IWS - Illinois State Water Survey
ODW - Ohio Department Natural Resources--Division of Water
SCS - Soil Conservation Service
TVA - Tennessee Valley Authority

FORM FOR REPORTING RESERVOIR SEDIMENTATION

A completed sample of the reservoir sedimentation data sheet from the supplement is shown on pages **F-79 and F-80**. This sheet is a convenient and standard form for reporting results of reservoir surveys. An invitation is extended to readers, particularly those practicing engineering individually, in engineering firms, or in local government agencies, to prepare sheets covering surveys known to them but not included in this publication. A blank "Reservoir Sedimentation Data" sheet is enclosed as a tear sheet on pages **F-81 and F-82**. Additional data sheets may be obtained from the department offices listed on the title page or the form may be reproduced if desired. The completed forms may be sent to any one of the agencies represented on the Sedimentation Committee for inclusion in supplements to this bulletin.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
ST. JOHN MACHIAS, PENOBSCOT, KENNEBEC, ANDROSCOGGIN, AND PRESUMPSCOT RIVER BASIN													
1-1	Little River Res. #2	Little River	Belfast, Me.	13.9	13.8	— 1913	--	456	*0,029	--	—	--	SCS
	do	do	do	—	--	Oct. 1969	56	341	.021	*100	0.15	326	
HOUSATONIC, CONNECTICUT, THAMES, AND MERRIMACK RIVER BASIN													
2-1	Broad Brook	Broad Brook River	Broad Brook, Conn.	5.13	—	— 1916	—	3,706	--	--	--	--	SCS
	do	do	do	--	—	Sept. 1951	35	3,652	--	*50	.33	359.4	
2-2	Mountain Street	Trib. of Beaver Brook	Greenfield, Mass.	.8	—	— 1905	—	1,074.2	--	—	--	--	SCS
	do	do	do	—	—	Sept. 1951	46	1,056.1	--	*50	.56	609.8	
2-3	Plants Pond	Eightmile Run	Plantsville, Conn.	15.76	--	Nov. 1850	—	105.0	--	--	--	—	SCS
	do	do	do	—	—	Sept. 1951	101	84.8	--	*50	.01	10.9	
2-4	Southington Reservoir	Budd River	Southington, Conn.	1.08	—	— 1883	—	321.8	--	—	--	—	SCS
	do	do	do	--	—	Sept. 1951	68	314.0	--	*50	.10	108.9	
2-5	Wallingford	Pine River	Wallingford, Conn.	8.98	—	— 1941	--	433.4	--	--	—	—	SCS
	do	do	do	--	—	Sept. 1951	10	430.0	—	*50	.04	43.6	
2-6	West Whately	Avery Brook	West Whately, Mass.	9.0	—	-- 1902	--	76.7	--	--	—	—	SCS
	do	do	do	—	—	Sept. 1951	49	71.2	--	*50	.012	13.07	
2-7	Westfield	Moose Mountain Branch	Westfield, Mass.	2.52	—	— 1874	—	564.6	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	77	546.8	--	*50	.094	102.4	
HUDSON RIVER BASIN AND ST. LAWRENCE DRAINAGE IN NEW YORK													
3-1	Schoharie (Gilboa Dam)	Schoharie Creek	Prattsville, N. Y.	314	312.32	Aug. 1926	—	63,821	--	--	—	--	SCS
	do	do	do	--	—	May 1950	23.8	62,702	—	*60	1/.166	1/217	
3-2	Englishtown Pond	Weamaconk Creek	Englishtown, N. J.	7.2	7.19	— 1755	—	42.3	.005	—	--	--	SCS
	do	do	do	—	—	Oct. 1955	200	13.5	.002	*60	.02	26.14	
3-3	Carnegie Lake	Millstone River	Princeton, N. J.	155	47.8	Dec. 1907	—	1,256	—	--	--	—	SCS
	do	do	do	—	—	Sept. 1950	42.8	954	--	*50	2/.20	217.8	
	do	1 do	do	--	--	— 1959	9.0	3/822	--	—	—	--	
3-4	Wappinger	Wappinger Creek	Wappinger Falls, N. Y.	197	—	— 1900	—	604.4	—	—	—	--	SCS
	do	do	do	--	—	July 1952	52	461.6	--	*50	.01	10.89	
SUSQUEHANNA AND DELAWARE RIVER BASINS													
4-1a	Loch Raven Reservoir	Gunpowder Falls River	Towson, Md.	303	4/219.4	— 1914	—	5/70,169	—	--	--	—	SCS
	do	do	do	—	—	Oct. 1943	29	5/64,813	—	*60	4/.618	4/808	
	do	do	do	—	—	June 1961	18	64,072	—	57.3	.187	233	
4-2a	Prettyboy	do	Herford, Md.	80	77.5	Apr. 1933	—	60,979	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1943	10.5	5/60,410	--	*60	.699	913	
	do	do	do	—	—	Sept. 1961	18	59,864	—	64.2	.391	547	
4-3	Griffin	Griffin Creek (Legget)	Scranton, Pa.	3.21	3.04	— 1888	—	1,991	—	—	—	--	SCS
	do	do	do	—	--	May 1941	53	1,953	--	—	.237	--	
4-4	Elmhurst	Roaring Brook	do	34.85	34.55	-- 1890	--	3,766	--	—	—	--	SCS
	do	do	do	--	—	May 1941	51	3,686	--	—	.034	—	
4-5	Lake Williams	Cordorus Creek	York, Pa.	42.9	42.6	--. 1912	--	2,686	—	--	—	--	SCS
	do	do	do	--	—	Apr. 1939	27	2,232	--	49.1	.394	421	
4-6	Williams Bridge	Stafford Meadow Brook	Scranton, Pa.	5.0	4.94	— 1893	—	1,051	--	--	—	--	SCS
	do	do	do	—	—	May 1941	48	1,046	--	--	.022	—	
4-7a	Atkisson Reservoir	Winter's Run	Bel Air, Md.	45.46	45.35	— 1942	--	896.19	.025	--	—	--	SCS
	do	do	do	—	—	— 1954	12	705.32	.019	*60	.351	459	
	do	do	do	--	--	— 1965	11	617.06	.017	--	.177	231	
4-8a	Palto Dam	Dean Creek	Spencer, N. Y.	.41	.41	July 1955	—	56.04	.130	--	—	—	SCS
	do	do	do	--	--	Aug. 1957	2	55.90	.129	*80	.170	296	
	do	do	do	—	—	June 1966	8.9	55.60	.128	*79.2	.083	141	
4-9a	Pylkas Dam	do	do	.71	.71	July 1955	—	187.31	.250	--	--	—	SCS
	do	do	do	--	--	Aug. 1957	2	187.13	.250	*80	.130	226.4	
	do	do	do	--	—	June 1966	8.9	186.70	.249	*80	.068	119	
4-10	Columbia Dam	Paulins Kill River	Columbia, N. J.	171	171	July 1937	—	311.77	--	--	--	--	SCS
	do	do	do	--	—	July 1957	20	244.19	—	*64	.02	28	

4-11	Old Glatfelter	W. Br. Codorus Creek	Spring Grove, Pa.	74.3	—	—	1884	—	147.2	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	55	10.0	—	—	.034	—	
4-12	Palington Reservoir	Powder Creek	do	2.91	2.90	—	1937	—	63.0	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	1.6	59.9	—	33.2	.669	483	
4-13	Lake Rushford	Caneadea Creek	Caneadea, N. Y.	60.7	—	—	1925	—	28,000	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1951	26	27,426	—	*60	.37	484	
4-14	Icedale	Brandywine W. Br.	Coatesville, Pa.	20.0	—	—	1900	—	137	—	—	—	—	SCS
	do	do	do	—	—	July	1951	51	106	—	*50	.03	33	
4-15	Coatesville	Rock Run	do	5.0	—	—	1916	—	1,019	—	—	—	—	SCS
	do	do	do	—	—	July	1951	35	970	—	*50	.28	305	
4-16	Liberty Reservoir	Patapsco	Wards Chapel, Md.	164	159.1	July	1954	—	138,762.4	1.133	—	—	—	SCS
	do	do	do	—	—	June	1962	7.9	138,227.0	1.129	*60	.426	557	
4-17	Little Deer No. 1	Cattail Branch	Madonna, Md.	.74	.73	June	1958	—	6/23.37	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1962	4.4	6/19.99	—	*60	6/1.055	1,378.7	
4-18	Mount Morris	Genesee River	Mount Morris, N. Y.	1,077	1,011	Nov.	1951	—	338,010	.347	—	—	—	CE
	do	do	do	—	—	May	1957	5.5	336,611	.345	7/—	.25	419	
	do	do	do	—	—	May	1963	5.9	335,393	.344	77	.20	335	
4-19	Patterson Creek #1	Patterson Creek	Bedwell, N. Y.	4.3	4.3	Oct.	1968	—	891.40	.229	—	—	—	SCS
	do	do	do	—	—	Oct.	1970	2	887.95	.228	*80	6/.40	6/696	
4-20	Little Choconut #2B	West Branch Little Choconut	Choconut Center, N. Y.	1.64	1.64	Oct.	1968	—	272	.183	—	—	—	SCS
	do	do	do	—	—	Oct.	1970	2	271.38	.182	*80	6/.19	6/331	
POTOMAC, RAPPAHANNOCK, YORK, AND JAMES RIVER BASINS														
5-1a	Lake Barcroft	Trib. of Potomac River	Falls Church, Va.	14.5	14.3	Jan.	1915	—	8/1,847	.142	—	—	—	SCS
	do	do	do	—	—	Feb.	1938	23.1	8/1,762	.134	*60	.257	336	
	do	do	do	—	—	Aug.	1957	19.5	9/2,092	.161	—	.728	950	
5-2	Pedlar	Pedlar River	Oronoco, Va.	33.21	33.07	Feb.	1907	—	1,860	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1938	31	1,723	—	—	.136	—	
5-3	Burnt Mills	N. W. Br. Anacostia River	Silver Spring, Md.	27.0	26.97	May	1930	—	181	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1938	7.8	95	—	*60	.408	533	
5-4b	Greenbelt Lake	Trib. of Indian Creek	Greenbelt, Md.	10/.82	.79	July	1936	—	196	*.312	—	—	—	SCS
	do	do	do	—	—	Feb.	1938	1.6	186	*.296	*60	7.91	10,337	
	do	do	do	—	—	Aug.	1957	19.5	151	*.240	*60	2.27	2,970	
	do	do	do	—	—	June	1968	10.8	11/147	.234	*60	1.52	1,945	
5-4a	Staunton	North River	Staunton, Va.	25	25	Dec.	1925	—	385	—	—	—	—	SCS
	do	do	do	—	—	Jan.	1940	14	373	—	—	.034	—	
	do	do	do	—	—	June	1957	17.5	350	—	—	.053	—	
5-6	Jackson	Occoquan Creek	Manassas, Va.	337	336.4	July	1930	—	4,500	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1937	7.2	4,158	—	*60	.161	184	
5-7b	Triadelphia L. (Brighton D.)	Patuxent River	Brighton, Md.	81.4	80.0	Jan.	1942	—	12/20,222	.327	—	—	—	SCS
	do	do	do	—	—	Oct.	1950	8.3	20,089	.324	*50	.20	218	
	do	do	do	—	—	Sept.	1958	7.9	19,633	.317	*50	.72	784	
	do	do	do	—	—	Aug.	1964	5.9	19,045	.308	61.1	1.25	1,663	
5-8	Gordon Lake	Evitts Creek	Cumberland, Md.	64	13/4	Sept.	1913	—	3,129	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1940	26.6	3,004	—	—	14/.090	—	
5-9	Thomas W. Koon Lake	do	do	60	59.6	Mar.	1932	—	7,312	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1940	8.1	7,294	—	—	.036	—	
5-10	Savage River Dam	Savage River	Bloomington, Md.	105.0	104.44	Mar.	1952	—	20,300	.172	—	—	—	SCS
	do	do	do	—	—	Mar.	1956	4.0	20,020	.169	*60	.643	840	
5-11	Rocky Gorge	Patuxent River	Laurel, Md.	132.8	50.14	Mar.	1954	—	21,390	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1964	10.4	20,789	—	67	1.15	1,678	
5-12	South River, Site 26	Inch Branch	Waynesboro, Va.	2.7	2.7	May	1956	—	610.4	.28	—	—	—	SCS
	do	do	do	—	—	Nov.	1970	14.5	607.0	.28	*60	.087	110	
5-13	Wilde Lake	Trib. Little Patuxent	Columbia, Md.	1.88	1.85	Sept.	1966	—	196.97	.140	—	—	—	SCS
	do	do	do	—	—	Aug.	1968	1.9	170.99	.122	*60	15/7.39	16/11,278	
	do	do	do	—	—	Aug.	1969	1.0	163.72	.117	*60	3.93	5,133	
CHOWAN, ROANOKE, TAR, NEUSE, AND CAPE FEAR RIVER BASINS														
6-1	Lake Apex	Swift Creek	Apex, N. C.	4.0	4.0	—	1925	—	106	—	—	—	—	SCS
	do	do	do	—	—	June	1941	16	94	—	—	.19	—	
6-2	Franklinton	Sallie Keaney Creek	Franklinton, N. C.	1.13	1.12	Jan.	1925	—	34.7	—	—	—	—	SCS
	do	do	do	—	—	May	1938	13.3	27.3	—	67	.509	743	
6-3	Greensboro (L. Brandt)	Reidy Fork	Greensboro, N. C.	74.1	73.4	Feb.	1923	—	2,870	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1934	11.5	2,610	—	*60	.308	402	
6-4	High Point	Deep River	High Point, N. C.	62.8	62.3	Jan.	1928	—	4,354	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1934	6.5	4,135	—	50.6	.541	596	
	do	do	do	—	—	Apr.	1938	3.75	4,038	—	—	.416	458	

1/ Includes estimated 112 acre-feet passing through Shandaken Tunnel.
2/ Includes 103 acre-feet of sediment dredged in 1937-1939.
3/ Partial survey covering segments 1-14 in Stoney Brook Arm Only.
4/ Net sediment contributing area was 299.4 sq. mi. until 1933 when Prettyboy Dam was completed. This area was used in the 1943 calculations.
5/ Revised after 1961 survey.
6/ Conservation or sediment pool only.
7/ Not determined - assumed equal to that determined in 1963.
8/ Based on original spillway crest elevation 205 feet m. s. l.
9/ Based on spillway crest elevation 210 feet m. s. l. and estimated capacity of 2,380 acre-feet resulting from 1942 addition to top of dam.
10/ Revised 1968.
11/ 9 acre-feet gained by dredging.
12/ Revised due to movable control gates.
13/ Koon Lake, upstream, was built in 1932.
14/ Based on total sediment in both Gordon Lake and Koon Lake.
15/ Does not include 4.34 acre-feet dredged.
16/ Includes 4.34 acre-feet dredged in early spring 1968.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY		PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET							AC.-FT.	TONS	
			CHOWAN, ROANOKE, TAR, NEUSE, AND CAPE FEAR RIVER BASINS (CONTINUED)											
6-5	Lake Michie	Flat River	Durham, N. C.	167.5	166.7	Apr.	1926	—	12,671	—	—	—	—	SCS
	do	do	do	—	—	Jan.	1935	8.75	12,276	—	—	0.271	—	
6-6	Sanford City	Lick Creek	Sanford, N. C.	3.75	3.73	Feb.	1927	—	103	—	—	—	—	SCS
	do	do	do	—	—	June	1943	16.33	95	—	—	.130	—	
6-7	University Lake	Morgan Creek	Chapel Hill, N. C.	30.6	30.3	June	1932	—	1,959	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1935	2.9	1,851	—	—	.728	—	
6-8	Roxboro City Lake	Satterfield Creek	Roxboro, N. C.	7.62	7.52	Apr.	1926	—	531.2	—	—	—	—	SCS
	do	do	do	—	—	June	1943	17.2	480.3	—	—	.368	—	
	do	do	do	—	—	Nov.	1948	5.4	468.4	—	—	1/.343	—	
6-9	Burlington Municipal	Stony Creek	Burlington, N. C.	105.2	105.0	June	1928	—	1,488	—	—	—	—	SCS
	do	do	do	—	—	May	1938	10.0	1,325	—	65	.155	213	
	do	do	do	—	—	Sept.	1949	11.3	1,202	—	—	.104	143	
6-10a	Walnut Cove	Dan River	Walnut Cove, N. C.	397	397	—	1926	—	976	.002	—	—	—	CE
	do	do	do	—	—	Apr.	1932	5/6	809	.002	*63	.216	300	
6-11	John H. Kerr	Roanoke River	South Hill, Va.	7,800	7,391	July	1952	—	2,808,600	.494	—	—	—	CE
	do	do	do	—	—	Dec.	1959	7.4	2,750,349	.484	38.6	1.06	796	
6-12	Philpott	Smith River	Bassett, Va.	212	185.7	Dec.	1951	—	201,900	.966	—	—	—	CE
	do	do	do	—	—	Nov.	1960	8.9	198,000	.949	46.2	2.08	2,105	
			PEE DEE, SANTEE, AND EDISTO RIVER BASINS											
7-1	Chester	Sandy River	Chester, S. C.	16.05	15.92	Nov.	1926	—	682	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1937	11	585	—	—	.55	—	
7-2	Lancaster	Turkey Quarter Creek	Lancaster, S. C.	9.40	9.34	Feb.	1925	—	243	—	—	—	—	SCS
	do	do	do	—	—	June	1938	13.4	190	—	66.3	.427	585	
7-3a	Spartanburg Municipal	South Pacolet River	Fingerville, S. C.	91.33	90.8	May	1926	—	1/3,506	—	—	—	—	SCS
	do	do	do	—	—	July	1934	8.2	1/3,199	—	—	1/.410	—	
	do	do	do	—	—	Mar.	1947	12.7	1/2,895	—	—	1/.268	—	
	do	do	do	—	—	Oct.	1955	18.6	1/2,593	—	—	1/.376	—	
	do	do	do	—	—	Oct.	1965	10.0	4/3,109	—	—	—	—	
7-4	Appalachia	South Tyger River	Greer, S. C.	63.0	62.8	—	1906	—	2,900	—	—	—	—	SCS
	do	do	do	—	—	July	1936	30	1,600	—	—	.48	—	
7-5	Albemarle City Lake	Long Creek	Albemarle, N. C.	33.0	32.5	Feb.	1924	—	1,070	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1939	15.5	918	—	—	.300	—	
7-6	Cannon Lake	Buffalo Creek	Kannapolis, N. C.	18.0	17.7	July	1939	—	2,400	—	—	—	—	SCS
	do	do	do	—	—	June	1941	1.9	2,374	—	—	.776	—	
7-7	Lake Concord	Chambers & Rose Branch	do	4.7	4.54	Mar.	1925	—	1,208	—	—	—	—	SCS
	do	do	do	—	—	May	1935	10.2	1,128	—	—	1.71	—	
7-8	Roberdell No. 3	Hitchcock Creek	Roberdell, N. C.	168.0	5/18.0	—	1892	—	186	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1940	48.0	163	—	—	.026	—	
7-9	Bury	Little River	Troy, N. C.	269	269	—	1915	—	1,104	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1940	25.0	976	—	—	.019	—	
7-10	High Rock	Yadkin River	Salisbury, N. C.	3,930	3,863	Nov.	1927	—	289,632	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1935	7.8	271,516	—	—	.603	—	
7-11	Lake Lee	Richardson Creek	Monroe, N. C.	50.50	50.34	Apr.	1927	—	731	—	—	—	—	SCS
	do	do	do	—	—	June	1938	11.1	653	—	61.6	.308	426	
7-12	Pee Dee Mfg. Co.	Hitchcock Creek	Rockingham, N. C.	196	5/25	—	1874	—	646	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1940	66	606	—	—	.036	—	
7-13	Salem	Salem Creek	Winston-Salem, N. C.	27.60	27.26	Nov.	1919	—	3,099	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1939	19.8	2,860	—	38.0	.444	397	
7-14	Norwood L. (Tillery)	Pee Dee River	Mt. Gilead, N. C.	4,600	6/431	July	1928	—	136,023	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1940	11.75	133,300	—	—	.098	—	
7-15	Lexington	Leonards Creek	Lexington, N. C.	6.75	6.66	Aug.	1935	—	462	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1940	4.8	443	—	65.5	.985	605	
	do	do	do	—	—	May	1951	11.1	419	—	*65.5	.299	290	
7-16	Third Creek Site No. 7	Third Creek	Statesville, N. C.	6.04	4.74	Sept.	1957	—	981.6	.186	—	—	—	SCS
	do	do	do	—	—	Mar.	1962	4.5	968.5	.186	2/62.2	.61	826	
	do	do	do	—	—	Mar.	1965	3.0	965.9	.183	2/62.2	.18	246	
	do	do	do	—	—	Apr.	1969	4.1	963.1	.183	2/62.2	.16	190	

			SAVANNAH, OGEECHEE, AND ALTAMAHA RIVER BASINS											
8-1	Lake Issaqueena	Six Mile Creek	Clemson, S. C.	14.02	8/13.84	June	1938	—	1,836	—	—	—	—	SCS
	◆	◆	◆	—	9/13.86	Apr.	1941	2.9	1,749	—	49.40	2.22	2,410	
	◆	◆	◆	—	—	Oct.	1949	8.5	1,[illegible]	—	90.9	1.05	1,340	
8-2	Lloyd Shoals	Ocmulgee River	Jackson, Ga.	1,414	1,407	Dec.	1910	—	112,530	—	—	—	—	SCS
	◆	◆	◆	—	—	Mar.	1935	24.3	98,970	—	960	.408	777	
8-3a	North Fork Broad No. 2	Denman's Creek	Toccoa, Ga.	.96	.94	Jan.	1956	—	10/198	.181	—	—	—	SCS
	◆	◆	◆	—	—	June	1959	3.4	196.2	.179	55.1	.383	695	
	◆	◆	◆	—	—	Apr.	1970	10.8	195.8	.176	55.1	.335	402	
8-4a	North Fork Broad No. 6	Bear Creek	Mize, Ga.	3.62	3.50	July	1956	—	10/780.9	.199	—	—	—	SCS
	◆	◆	◆	—	—	June	1959	2.92	770.6	.197	74.8	1.01	1,445	
	◆	◆	◆	—	—	Apr.	1970	10.8	751.55	.192	74.8	.50	814	
8-5a	North Fork Broad No. 11	Tom's Creek	Eastanollee, Ga.	3.79	3.67	July	1956	—	10/795.4	.193	—	—	—	SCS
	◆	◆	◆	—	—	June	1959	2.9	777.4	.190	73.8	1.39	2,274	
	◆	◆	◆	—	—	Apr.	1970	10.9	763.9	.186	73.8	.34	567	
8-6	North Fork Broad No. 1	North Fork Broad River	Toccoa, Ga.	3.73	3.70	June	1958	—	633.2	.168	—	—	—	SCS
	◆	◆	◆	—	—	Apr.	1970	11.9	626.16	.166	65.2	.025	280	
8-7	North Fork Broad No. 14	Tom's Creek	◆	1.2	1.191	Oct.	1956	—	288.1	—	—	—	—	SCS
	◆	◆	◆	—	—	Mar.	1963	7.4	276.8	—	11/58.6	.65	738	
	◆	◆	◆	—	—	Nov.	1966	2.7	272.0	—	—	1.69	—	
	◆	◆	◆	—	—	Apr.	1969	6.5	267.0	—	12/64.2	.95	1,341	
			SATILLA, ST. MARYS, ST. JOHNS, AND SUWANNEE RIVER BASINS											
9-														
			SOUTHERN FLORIDA DRAINAGE											
10-														
			APALACHICOLA AND OCHLOCKONEE RIVER BASINS											
11-1	Newnan	Sellers Mill Creek	Newnan, Ga.	1.39	1.34	June	1924	—	384	—	—	—	—	SCS
	◆	◆	◆	—	—	Nov.	1937	13.6	338	—	*30	1.45	3,980	
	◆	◆	◆	—	—	Feb.	1965	7.3	354	—	—	.45	446	
11-2	Sky Lake	Trib. of Chickamauga Creek	Helen, Ga.	2.34	2.31	June	1935	—	214.6	—	—	—	—	SCS
	◆	◆	◆	—	—	May	1956	21	170.6	—	67	.58	646	
11-3	Sautee Creek Site #3	Bear Creek	Cleveland, Ga.	2.9	2.8	Dec.	1959	—	654.8	.116	—	—	—	SCS
	◆	◆	◆	—	—	Nov.	1970	10.9	555.2	.095	75.8	3.92	6,477	
			CHOCTAWHATCHEE, YELLOW, ESCAMBIA, AND ALABAMA RIVER BASINS											
12-1	Sequoyah	Small Branches	Jasper, Ga.	1.60	1.51	July	1929	—	890	—	—	—	—	SCS
	◆	◆	◆	—	—	July	1939	10.0	865	—	—	1.66	—	
12-2	White Manganese No. 6	Pettit Creek	Cartersville, Ga.	12.46	13/11.0	Oct.	1929	—	1,091	—	—	—	—	SCS
	◆	◆	◆	—	—	Nov.	1938	9.2	930	—	63.7	1.30	1,680	
12-3	Lake Auburn	Town Creek (Trib. of)	Auburn, Ala.	1.6	1.6	Feb.	1931	—	108	—	—	—	—	SCS
	◆	◆	◆	—	—	June	1937	6.3	95	—	—	.46	—	
12-4	Lay	Coosa River	Clanton, Ala.	9,087	9,076.5	Dec.	1913	—	156,525	.016	—	—	—	SCS
	◆	◆	◆	—	—	May	1936	22.3	130,580	.013	—	.009	—	
12-5	Lake Purdy	Little Cahaba River	Birmingham, Ala.	41.74	40.22	Sept.	1930	—	19,080	—	—	—	—	SCS
	◆	◆	◆	—	—	Nov.	1955	25.2	18,994	—	—	.479	—	
12-6	Carroll Lake	Curtis Creek	Carrollton, Ga.	7.43	7.18	Oct.	1960	—	1,448.0	.182	—	—	—	SCS
	◆	◆	◆	—	—	May	1967	6.5	1,325.6	.167	62.5	2.0	1,890	
12-7	Temple Reservoir	Webster Branch	Temple, Ga.	.63	.61	June	1954	—	65.5	.097	—	—	—	SCS
	◆	◆	◆	—	—	May	1957	3	60.5	.090	66.3	2.76	2,420	
12-8	High Pine Dam No. 5	Trib. of High Pine	Roanoke, Ala.	1.8	1.55	Mar.	1961	—	389.7	*.163	—	—	—	
	◆	◆	◆	—	—	May	1970	9.17	365.3	*.161	14/53.09	.52	596.3	SCS
			TOMBIGBEE, PASCAGOULA, AND PEARL RIVER BASINS											
13-1	Bayview	Village Creek	Birmingham, Ala.	72.3	71.6	May	1911	—	11,666	—	—	—	—	SCS
	◆	◆	◆	—	—	Dec.	1935	24.6	9,516	—	—	3.36	—	
13-2a	Lake Harris	Yellow Creek	Tuscaloosa, Ala.	30.0	29.6	Feb.	1929	—	2,421	.061	—	—	—	SCS
	◆	◆	◆	—	—	Nov.	1935	6.75	2,373	.059	—	.239	—	
	◆	◆	◆	—	—	Aug.	1953	17.75	15/2,436	.056	99.9	.120	346	
13-3	W. C. Crain Farm Pond #3	Bogue Lusa Creek	Bogalusa, La.	.13	.13	Aug.	1949	—	7.631	.064	—	—	—	SCS
	◆	◆	◆	—	—	May	1963	13.5	6.983	.060	—	.377	—	
			LOWER MISSISSIPPI RIVER BASIN (NATCHEZ TO THE MOUTH) Calcasieu, Mermentau, and Vermilion River Basins											
14-														

1/ Excluding 2.0h acre-feet of sediment dredged from lake in March 1942.
2/ Assume storage depletion occurred in 9 years, see H. D. 65, 75th Congress, 1st. session ("308" report).
3/ Elevation of dam raised from 775.0 to 777.1 feet Sept. 1956. Data based on original elevation of 775.0 feet and original capacity of 3906 ac.-ft.
4/ Present storage capacity at elevation 777.1 feet.
5/ LeBatiers' dam contract
6/ Narrows upstream
7/ Average of 90 samples collected in 1962.
8/ In 1940
9/ In 1949
10/ Changed on basis of 1970 survey.
11/ Average of 9 samples.
12/ Average of 10 samples.
13/ Drainage area above reservoir No. 3 excluded.
14/ Weighted average: Submerged sediment 51.75 pcf; aerated assumed 69 pcf.
15/ With 5-foot flashboards added in 1947.
* Estimated or assumed.

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SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	LOWER MISSISSIPPI RIVER BASINS (HELENA TO NATCHEZ) Yazoo, Big Black, and Ouachita River Basins												
15-1	Lake Hamilton	Ouachita River	Hot Springs, Ark.	1,421	1,413.4	Dec. 1930	--	156,345	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	May 1950	19.4	153,279	--	*50	0.11	120	
15-2	Lake Winona	Alum Fork Saline River	Little Rock, Ark.	43.0	41.3	Oct. 1937	--	34,513	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	May 1950	12.6	34,340	--	*50	.37	403	
15-3	O. P. White Pond	Trib. of Chewalla Creek	Holly Springs, Miss.	.0097	.0089	Oct. 1947	--	1.46	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	3.3	1.07	--	63.64	13.1	18,200	
15-4	D. W. Hennessecker Pond	Trib. of Coldwater River	Slayden, Miss.	.0623	.0597	Jan. 1947	—	12.0	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	4.0	8.35	--	60.09	15.3	20,000	
15-5	C. S. Hurdle Pond	-do-	-do-	.244	.234	Dec. 1946	—	36.4	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	4.1	29.0	--	62.9	7.78	10,700	
15-6	Agnes Jones Pond	Trib. of Coldwater River	Holly Springs, Miss.	.0478	.0451	Oct. 1946	--	8.80	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	4.3	6.40	--	67.27	12.4	18,200	
15-7	Lee Johnson Pond	Trib. of Red Banks Creek	-do-	.0833	.0784	Sept. 1948	—	17.8	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	2.3	14.8	--	76.13	16.6	27,500	
15-8	P. T. McAlexander	Trib. of Coldwater River	-do-	.0139	.0128	Aug. 1942	—	2.46	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Jan. 1951	8.4	1.11	--	84.26	12.6	23,100	
15-9	Lake Shabocka	Trib. of Camp Creek	Olive Branch, Miss.	.4153	.3663	Jan. 1934	--	306	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	17.0	256	--	61.65	8.03	10,800	
15-10	Lake Woodland	-do-	-do-	.5045	.4797	Feb. 1945	--	94	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	6.0	78.1	--	39.9	5.52	4,800	
15-11	C. L. Patton Pond	Trib. of Red Banks Creek	Warsaw, Miss.	.1019	.0956	Feb. 1942	—	14.9	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	9.0	11.1	--	66.8	4.48	6,520	
15-12	G. D. Langston, Jr., Pond	Trib. of Red Banks Creek	Warsaw, Miss.	.0196	.0116	Feb. 1916	—	12.1	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	35.0	9.66	--	63.3	6.55	9,040	
15-13	Fletcher Hurdle Pond (North)	Trib. of Byhalia Creek	Victoria, Miss.	.0406	.0389	Feb. 1947	--	4.61	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	4.0	2.67	--	63.0	12.5	17,150	
15-14	Fletcher Hurdle Pond (South)	-do-	-do-	.0297	.0279	Feb. 1947	—	5.48	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	4.0	3.61	--	83.1	16.8	30,400	
15-15	G. G. Stevenson Pond	Trib. of Cuffawa Creek	Holly Springs, Miss.	.0342	.0320	Aug. 1948	--	6.67	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	2.7	4.23	--	78.8	26.0	44,600	
15-16	Gayoso Lake	Trib. of Mississippi River	Horn Lake, Miss.	.2196	.2047	Feb. 1942	--	58.7	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	9.0	53.0	--	55.85	3.13	3,550	
15-17	Ben O. Pettis Pond	Trib. of Toby Tubby Creek	Oxford, Miss.	.0075	.0067	Feb. 1916	—	1.63	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Feb. 1951	35.0	1.07	--	58.72	2.39	3,060	
15-18	C. D. Williams Pond	Trib. of Hudson Creek	-do-	.0450	.0418	Mar. 1928	--	9.93	--	--	--	--	SCS
	-do-	-do-	-do-	—	--	Mar. 1951	23.0	6.70	--	55.72	3.35	4,070	
15-19	R. E. Williams	Trib. of Yocona River	Taylor, Miss.	.0239	.0210	Sept. 1946	--	4.48	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Mar. 1951	4.5	2.54	--	67.76	20.5	30,300	
15-20	Henry W. Ramsey Pond	Trib. of Sarter Creek	Oxford, Miss.	.1375	.1289	Jan. 1933	--	31.0	--	--	--	--	SCS
	-do-	-do-	-do-	--	--	Mar. 1951	18.2	24.9	--	41.75	2.61	2,370	
15-21	Dr. Bramlett Pond	Trib. of Pumpkin Creek	-do-	.8672	.8131	Jan. 1937	--	227	--	--	--	--	SCS
	-do-	-do-	-do-	—	--	Mar. 1951	14.2	214	--	*37	1.12	913	
15-22	A. S. Ryle Pond	Trib. of Tallahatchie R.	Batesville, Miss.	.0456	.0398	Mar. 1945	--	17.6	--	--	--	--	SCS
	-do-	-do-	-do-	--	—	Mar. 1951	6.0	16.6	--	52.04	3.16	3,580	
15-23	Sam P. Smith Pond	Trib. of Pigeon Roost Cr.	Holly Springs, Miss.	.0278	.0264	July 1947	--	3.77	--	--	--	--	SCS
	-do-	-do-	-do-	--	—	Mar. 1951	3.7	3.29	--	67.58	4.89	7,200	
15-24	A. L. Rodman Pond	Trib. of Arkabutla Creek	Arkabutla, Miss.	.1563	.1458	Sept. 1945	--	30.5	--	--	--	--	SCS
	-do-	-do-	-do-	—	—	Mar. 1951	5.5	29.0	--	*50	1.95	2,120	
15-25	Charles Dockery Pond	Trib. of Hurricane Creek	Eudora, Miss.	.0644	.0566	Jan. 1946	--	23.0	--	--	--	--	SCS
	-do-	-do-	-do-	--	--	Mar. 1951	5.2	22.0	--	*46	3.40	3,420	
15-26b	Arkabutla Reservoir	Coldwater River	Arkabutla, Miss.	1,000	948	Apr. 1939	--	529,300	.499	--	--	--	[illegible]
	-do-	-do-	-do-	—	—	Dec. 1947	8.71	525,560	.495	*60	.427	558	
	-do-	-do-	-do-	--	—	May 1962	14.42	513,060	.487	*60	.620	810	
15-27a	W. W. Murphy Pond	Trib. of Jones Creek	Holly Springs, Miss.	.208	.200	Nov. 1953	--	1/22.68	*.194	--	--	--	ARS
	-do-	-do-	-do-	--	—	May 1956	2.5	19.72	*.169	*90	2/8.4	2/16,465.7	
	-do-	-do-	-do-	--	—	Sept. 1959	3.3	17.86	*.152	*90	2/3.8	2/7,448.8	
	-do-	-do-	-do-	--	--	Nov. 1963	4.2	15.77	*.135	*90	2/3.5	2/6,860.7	
15-28a	Powerline Dam	East Goose Creek	Oxford, Miss.	.486	.477	Apr. 1953	—	1/30.54	--	--	--	--	ARS
	-do-	-do-	-do-	--	--	May 1955	2.1	26.26	--	66	2/5.66	2/8,136.1	
	-do-	-do-	-do-	--	--	Oct. 1958	3.4	21.36	--	70	2/5.87	2/8,949.4	
	-do-	-do-	-do-	--	--	June 1960	1.66	20.07	--	70	2/5.30	2/8,080.4	
	-do-	-do-	-do-	--	--	Aug. 1962	2.15	19.40	--	*70	2/1.38	2/2,103.9	

15-29a	Andrew Smith Pond	Trib. of Jones Creek	Holly Springs, Miss.	.327	.300	Nov.	1953	—	1/22.72	*.133	—	—	—	ARS
	-do-	-do-	-do-	—	—	May	1956	2.5	18.83	*.102	*90	2/6.2	2/12,193.2	
	-do-	-do-	-do-	—	—	Sept.	1959	3.3	17.77	*.096	*90	2/2.07	2/4,797.6	
	-do-	-do-	-do-	—	—	Nov.	1963	4.3	16.47	*.089	*90	2/1.47	2/3,465.6	
15-30a	Sardis Reservoir	Little Tallahatchie River	Sardis, Miss.	1,545	1,454	Mar.	1937	—	1,569,900	.936	—	—	—	CE
	-do-	-do-	-do-	—	—	May	1960	20.6	1,549,336	.922	*60	.487	898	
15-31	Enid Reservoir	Yocona River	Enid, Miss.	560	516	—	1960	—	660,030	1.073	—	—	—	CE
	-do-	-do-	-do-	—	—	—	1951 3/	—	—	—	—	—	—	
	-do-	-do-	-do-	—	—	May	1961	9.83	697,808	1.068	*60	.558	729	
15-32	Grenada Reservoir	Yalobusha River	Grenada, Miss.	1,320	1,219	—	1962	—	1,337,400	.969	—	—	—	CE
	-do-	-do-	-do-	—	—	July	1953 4/	—	—	—	—	—	—	
	-do-	-do-	-do-	—	—	May	1965	11.83	1,330,000	.957	*60	1.205	1,575	
			LOWER MISSISSIPPI RIVER BASIN (CHESTER TO HELENA) St. Francis River Basin											
16-1	Grisham	Lost Creek	Bismark, Mo.	.46	.45	Oct.	1930	—	24.05	*.077	—	—	—	SCS
	-do-	-do-	-do-	—	—	July	1939	8.8	19.56	*.063	75.4	1.133	1,860	
16-2	Mountain Lake	Trib. of Rings Creek	Patterson, Mo.	1.90	1.87	—	1927	—	87.7	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	July	1939	12	82.9	—	56.8	.213	256	
16-3	Shepherd Mountain	Trib. of Stouts Creek	Ironton, Mo.	3.99	3.96	—	1929	—	171	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	July	1939	10	158	—	66	.338	471	
16-4	Loch Mary	Brown Creek	Earlington, Ky.	3.81	3.65	—	1888	—	1,228	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Dec.	1908	20	1,184	—	*60	.600	784	
16-5	Carbondale	Piles Fork	Carbondale, Ill.	3.00	2.77	Aug.	1926	—	1,380	—	—	—	—	SWS
	-do-	-do-	-do-	—	—	Sept.	1948	22.1	1,193	—	73.9	3.15	5,090	
16-6	Dering Coal Co. Pond	Trib. of Wolf Creek	Eldorado, Ill.	.219	.206	—	1919	—	89.3	—	—	—	—	SWS
	-do-	-do-	-do-	—	—	Oct.	1949	30	73.0	—	*76	2.64	4,590	
16-7	Eldorado	Wolf Creek	-do-	2.23	1.87	Oct.	1920	—	844.6	—	—	—	—	SWS
	-do-	-do-	-do-	—	—	Oct.	1949	29	736.0	—	*67	2.18	3,180	
16-8	West Frankfort	Tilley Creek	West Frankfort, Ill.	4.03	3.75	Aug.	1926	—	5/1,608.6	—	—	—	—	SWS
	-do-	-do-	-do-	—	—	Sept.	1936	10.1	1,515.0	—	—	2.46	—	
	-do-	-do-	-do-	—	—	July	1949	12.8	1,487.8	—	—	6/.953	—	
16-9	Pineview (Lower)	South Fork Jonson Creek	Farmington, Mo.	.63	.07	—	1932	—	8.9	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	—	1939	7	8.2	—	*60	1.43	1,870	
16-10	Pineview (Middle)	-do-	-do-	.56	.06	—	1930	—	30.9	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	—	1939	9	29.1	—	*60	3.3	4,300	
16-11	Pineview (Upper)	-do-	-do-	.49	.48	—	1928	—	6.2	*.025	—	—	—	SCS
	-do-	-do-	-do-	—	—	—	1939 7/	10	5.6	*.016	*65	.583	825	
16-12	Killarney	Big Creek	Annapolis, Mo.	51	51	—	1910	—	818	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	—	1939	29	622	—	*60	.133	176	
16-13a	Wappapello	St. Francis River	Poplar Bluff, Mo.	1,310	1,206	July	1940 8/	—	625,000	.560	—	—	—	CE
	-do-	-do-	-do-	—	—	July	1947	7.0	624,651	.559	—	9/.0624	—	
	-do-	-do-	-do-	—	—	Mar.	1964	16.7	613,161	.550	—	.5705	—	
16-14a	Lake Miller	Casey Fork	Mt. Vernon, Ill.	4.65	4.43	Feb.	1944	—	1,746	.413	—	—	—	SWS
	-do-	-do-	-do-	—	—	June	1960	16.3	1,659	.582	36.0	1.20	898	
16-15	Flocks Lake	Unnamed	Marion, Ill.	.339	.316	—	1919	—	58.1	.265	—	—	—	SWS
	-do-	-do-	-do-	—	—	—	1951	32	46.8	.214	56.6	1.11	1,366	
16-16	Baker's Lake	-do-	-do-	.26	.25	—	1937	—	26.0	.143	—	—	—	SWS
	-do-	-do-	-do-	—	—	Aug.	1951	14	21.7	.129	36.8	.66	522	
16-17	Crab Orchard Lake	Crab Orchard Creek	Carbondale, Ill.	172	160	May	1940	—	67,320	.611	—	—	—	SWS
	-do-	-do-	-do-	—	—	July	1951	11.2	63,896	.580	47.5	1.95	1,976	
16-18	Marion	Limb Branch	Marion, Ill.	6.5	6.31	—	1921	—	705	.160	—	—	—	SWS
	-do-	-do-	-do-	—	—	July	1951	30	593	.141	34.5	.61	658	
16-19	Little Grassy Lake	Little Grassy	Carbondale, Ill.	15.7	14.2	Mar.	1942	—	25,761	2.563	—	—	—	SWS
	-do-	-do-	-do-	—	—	July	1951	9.3	25,365	2.506	38.7	2.85	2,602	
16-20	Herrin Reservoir No. 1	Unnamed	Herrin, Ill.	1.78	1.70	—	1913	—	199	.373	—	—	—	SWS
	-do-	-do-	-do-	—	—	—	1951	38	178	.335	27.5	.32	192	
16-21	Knights of Pythias Lake	-do-	Marion, Ill.	.33	.32	Dec.	1925	—	76.6	.350	—	—	—	SWS
	-do-	-do-	-do-	—	—	Aug.	1951	25.7	64.7	.306	62.9	1.22	1,671	
16-22a	Lake Ashley	Trib. of Muddy River	Ashley, Ill.	1.24	1.22	—	1941	—	150	.208	—	—	—	SWS
	-do-	-do-	-do-	—	—	Aug.	1956	15	138	.184	66.5	.49	692	
16-23	Christopher	Trib. of King Creek	Christopher, Ill.	.925	.858	—	1925	—	383.96	.598	—	—	—	SWS
	-do-	-do-	-do-	—	—	July	1960	35	353.59	.551	77.1	1.08	816.1	

1/ Sediment or conservation pool only.
2/ Includes sediment within original flow line of reservoir and above conservation pool.
3/ Original sediment range surveys.
4/ Used as beginning date of sediment deposits.
5/ Spillway crest raised from 439 to 441.77 ft. m.s.l. in April 1943. All data computed on basis of 441.77 ft. at spillway elevation.

6/ Net sediment volume in 1949 was 120.5 ac.-ft. due to compaction of earlier deposits.
7/ Dam failed spring 1938, survey conducted July 26, 1939.
8/ Original data from topographic survey of 1935-36.
9/ Based on incomplete resurvey; 1963 value of 0.57 is more reliable.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	LOWER MISSISSIPPI RIVER BASIN (CHESTER TO HELENA) St. Francis River Basin (Continued)												
16-24	Lake DuQuoin	Reese Creek	DuQuoin, Ill.	10.73	10.35	-- 1937	--	2,003	.316	--	--	--	IWS
	do	do	do	--	--	July 1957	20	1,870	.295	38.3	0.64	534	
16-25	W. F. Farrell	Trib. of Harper Creek	Mt. Vernon, Ill.	.519	.512	-- 1945	--	35.56	.103	--	--	--	IWS
	do	do	do	--	--	June 1960	15	27.41	.079	51.5	1.06	1,189	
16-26a	ICRR at Thompsonville	Trib. of Ewing Creek	Thompsonville, Ill.	1.799	1.725	-- 1926	--	352.44	.283	--	--	--	IWS
	do	do	do	--	--	Aug. 1960	34	300.63	.241	48.7	.880	934	
16-27	Lake Johnston City	Lake Creek	Johnston City, Ill.	3.85	3.75	-- 1922	--	471	.195	--	--	--	IWS
	do	do	do	--	--	Aug. 1957	35	394	.163	48.3	.59	620	
16-28	Valier Outing Club	Andy Creek	Valier, Ill.	2.47	2.37	-- 1922	--	369	.208	--	--	--	IWS
	do	do	do	--	--	Aug. 1957	35	320	.180	41.17	.59	530	
16-29	West Frankfort (New)	Stevens Creek	West Frankfort, Ill.	7.622	7.288	-- 1945	--	2,654.7	.502	--	--	--	IWS
	do	do	do	--	--	July 1960	15	2,390.9	.453	35.9	2.41	1,884.4	
16-30	Lake Reel-Em-In (Walker Lake)	Unnamed	Dixon, Ky.	2.05	1.96	-- 1948	--	659.0	.378	--	--	--	SCS
	do	do	do	--	--	May 1964	16	515.4	.296	*65	4.6	6,512.2	
16-31	Rough River FRS No. 1	Buffalo Creek	Kingswood, Ky.	2.86	2.85	Nov. 1955	--	617	.238	--	--	--	SCS
	do	do	do	--	--	June 1970	14.64	596.12	.290	56.13	1/.50	1/611	
16-32	Obion Creek FRS #24	Unnamed Trib. Little Creek	Fancy Farm, Ky.	.37	.36	Nov. 1960	--	1/30.35	*.23	--	--	--	SCS
	do	do	do	--	--	Nov. 1965	5	1/28.80	*.22	*80	1/.86	1/1,498	
16-33	Mud River FRS No. 14	Antioch Creek	Sharon Grove, Ky.	8.59	8.56	Jan. 1964	--	1,379.87	.15	--	--	--	SCS
	do	do	do	--	--	May 1970	6.33	1,355.49	.15	75.78	1/.45	1/742	
16-34	Caney Creek MPS #2	Bennett Fork	Caneyville, Ky.	5.77	5.65	Nov. 1965	--	--	--	--	--	--	SCS
	do	do	do	--	--	May 1970	4.5	1,355.4	.33	77.75	1/1.01	1/1,710	
16-35	Big Reedy FRS #9	West Fork	Reedyville, Ky.	6.76	6.69	June 1964	--	998	.154	--	--	--	SCS
	do	do	do	--	--	Apr. 1970	5.9	976.95	.190	77.58	1/.54	1/912.4	
	OHIO RIVER BASIN (MADISON TO UNIONTOWN) Wabash River Basin												
17-1	Huntingburg (Upper)	Trib. of Patoka River	Huntingburg, Ind.	.67	.63	July 1894	--	137	*.264	--	--	--	SCS
	do	do	do	--	--	Oct. 1940	46.3	119	*.229	*40	.617	538	
17-2a	Oakland City #2	S. Fork Patoka River	Oakland City, Ind.	.52	.40	-- 1921	--	2/850.8	*2.116	--	--	--	SCS
	do	do	do	--	--	Sept. 1940	19.0	2/835.8	*2.079	*40	1.937	1,720	
	do	do	do	--	--	Aug. 1965	24.9	811.0	*2.017	70	2.490	3,796	
17-3	Shafer Lake	Tippecanoe River	Monticello, Ind.	1,700	1,698	June 1923	--	14,722	*.016	--	--	--	SCS
	do	do	do	--	--	Aug. 1940	17.2	14,041	*.016	*75	.023	38	
17-4	Spring Mill	Mill Creek	Mitchell, Ind.	15.03	3/5.29	Oct. 1938	--	178	--	--	--	--	SCS
	do	do	do	--	--	Sept. 1948	9.9	127	--	*67	.975	1,420	
17-5	Greendale Lake	Connor's Branch	Xenia, Ill.	25.1	25.0	Aug. 1927	--	306	*.023	--	--	--	SCS
	do	do	do	--	--	Sept. 1940	13.1	260	*.020	*70	.160	213	
17-6	Ridge Lake	Trib. of Embarrass River	Charleston, Ill.	1.41	1.38	Apr. 1941	--	187.4	--	--	--	--	IWS
	do	do	do	--	--	Sept. 1947	6.4	171.9	--	72.4	1.75	2,760	
17-7	Vermilion Lake	N. Fork Vermilion River	Danville, Ill.	267	266	June 1915	--	4/8,643	*.061	--	--	--	SCS
	do	do	do	--	--	Oct. 1940	25.3	7,438	*.052	*70	.179	273	
17-8	Brown Park Lake	Trib. of Raccoon Creek	Flora, Ill.	1.34	1.33	-- 1938	--	49.08	.057	--	--	--	IWS
	do	do	do	--	--	June 1959	21	37.75	.044	58.6	.40	510.5	
17-9	Craig & Davidson's Lake	do	Martinsville, Ill.	.465	.427	-- 1947	--	187.75	.631	--	--	--	IWS
	do	do	do	--	--	June 1959	12	175.18	.588	33.14	2.46	1,775.6	
17-10	Farina Lake	None	Laclede, Ill.	.538	.531	-- 1928	--	16.4	.057	--	--	--	IWS
	do	do	do	--	--	Aug. 1958	30	13.3	.046	61.94	.19	256.35	
17-11	Graham Lake	Trib. of Veale Creek	Washington, Ind.	.34	.31	Aug. 1950	--	106.8	--	--	--	--	SCS
	do	do	do	--	--	Aug. 1956	6	106.4	--	--	.218	--	
17-12a	ICRR at Bluford	Fourmile Creek	Bluford, Ill.	3.353	3.199	-- 1926	--	670.7	.300	--	--	--	IWS
	do	do	do	--	--	June 1960	34	609.70	.273	43.5	.565	493	
17-13	Jones Pond	Trib. of Flat Creek	Otwell, Ind.	.034	.031	Oct. 1954	--	10.7	--	--	--	--	SCS
	do	do	do	--	--	Apr. 1956	1.5	10.6	--	--	2.10	--	
17-14a	Olney Reservoir (New)	Trib. of East Fork	Olney, Ill.	3.36	3.15	Sept. 1954	--	1,555.3	.723	--	--	--	IWS
	do	do	do	--	--	Aug. 1960	6.9	1,517.4	.706	30.3	1.70	1,460	
17-15	Patterson Lake	Trib. of Dismal Creek	Edgewood, Ill.	.959	.912	-- 1926	--	316.75	.516	--	--	--	IWS
	do	do	do	--	--	July 1959	33	281.09	.458	48.54	1.18	1,247.5	
17-16a	Plum Creek No. 15	Little Plum Creek	Taylorsville, Ky.	1.03	1.02	Sept. 1956	--	224.3	.268	--	--	--	SCS
	do	do	do	--	--	Apr. 1959	2.5	219.6	.262	45	1.84	1,803	
	do	do	do	--	--	Oct. 1960	1.5	213.2	.254	53	4.19	4,837	
17-17	Plum Creek No. 17	Trib. of Little Plum Creek	do	.56	.55	Dec. 1956	--	126.3	.263	--	--	--	SCS
	do	do	do	--	--	Apr. 1959	2.33	123.7	.258	56	2.00	2,439	
	do	do	do	--	--	Oct. 1960	1.5	121.2	.252	47	3.11	3,180	
17-18	Steiner Lake	Trib. of Pond Creek	Fairfield, Ill.	.308	.295	-- 1945	--	53.68	.261	--	--	--	IWS
	do	do	do	--	--	June 1960	15	48.62	.237	41.3	1.15	1,034.3	

17-19	Stevenson's Lake	Trib. of Kettering Branch	Martinsville, Ill.	.342	.327	—	1950	—	52.11	.238	—	—	—	IWS
	do	do	do	—	—	June	1959	9	46.5	.212	60.0	1.89	1,975.9	
17-20	Vevay Park Lake	Trib. of Range Creek	Greenup, Ill.	.294	.278	—	1906	—	67.41	.391	—	—	—	IWS
	do	do	do	—	—	June	1959	53	54.50	.316	47.61	.87	902.1	
17-21	Beaver Lake	Beaver Creek	Dubois, Ind.	3.95	3.57	Oct.	1955	—	2,486.0	*.787	—	—	—	SCS
	do	do	do	—	—	Oct.	1964	9	2,409.8	*.763	55	2.38	2,851	
17-22	Scottsburg Lake	Trib. of Muscatatuck	Scottsburg, Ind.	2.98	2.98	Fall	1949	—	749.02	*.296	—	—	—	SCS
	do	do	do	—	—	Oct.	1961	12	713.24	*.280	60.8	1.00	1,324.2	
17-23	Cagles Mill (Cataract Lake)	Mill Creek	Cloverdale, Ind.	295	287	Dec.	1952	—	5/232,370	1.123	—	—	—	CE
	do	do	do	—	—	Feb.	1962	9.17	230,906	1.116	62.8	.54	739	

TENNESSEE RIVER BASIN (BELOW HALES BAR DAM)
Cumberland and Green River Basins

18-1	Radnor Lake	Other Creek	Nashville, Tenn.	2.1	2.0	Mar.	1915	—	1,313	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1940	25.7	1,279	—	—	.660	—	
18-2a	Lake Tandy	Little River	Hopkinsville, Ky.	6.10	6.00	—	1907	—	769	.135	—	—	—	SCS
	do	do	do	—	—	Jan.	1941	34	564	.099	43	1.00	936	
	do	do	do	—	—	June	1959	18.5	509	.089	43	.495	463	
18-3c	Great Falls	Caney Fork River	Rock Island, Tenn.	1,675	1,671	Sept.	1935	—	54,925	.024	—	—	—	TVA
	do	do	do	—	—	Aug.	1947	12.0	52,370	.023	*60	.127	166	
	do	do	do	—	—	Jan.	1954	6.4	51,836	.023	*60	.050	65	
	do	do	do	—	—	Sept.	1960	6.6	51,591	.022	*60	.022	29	
	do	do	do	—	—	Nov.	1969	9.2	51,281	.023	*60	.02	26	
18-4c	Guntersville	Tennessee River	Guntersville, Ala.	24,450	2,550	Nov.	1940	—	1,097,380	—	—	—	—	TVA
	do	do	do	—	—	June	1947	6.6	1,080,897	—	*55	.979	1,173	
	do	do	do	—	—	May	1956	8.9	1,073,164	—	*55	.341	408	
	do	do	do	—	—	July	1961	5.1	1,064,228	—	*55	.687	823	
18-5c	Wheeler	do	Town Creek, Ala.	29,590	6/5,033	Oct.	1936	—	7/1,122,000	—	—	—	—	TVA
	do	do	do	—	—	June	1947	10.7	7/1,071,717	—	*55	8/—	8/—	
	do	do	do	—	—	May	1953	6.0	8/1,061,411	—	*55	.341	408	
	do	do	do	—	—	June	1956	3.0	1,061,005	—	*55	.027	32	
	do	do	do	—	—	Aug.	1961	5.1	1,050,303	—	*55	.417	500	
18-6c	Wilson	do	Florence, Ala.	30,750	1,135	Dec.	1928	—	687,000	—	—	—	—	TVA
	do	do	do	—	—	Dec.	1931	3.0	674,000	—	*53	9/.479	552.9	
	do	do	do	—	—	Dec.	1936	5.0	652,000	—	*53	9/.490	565.6	
	do	do	do	—	—	Sept.	1946	9.8	651,000	—	*53	10/.120	138.5	
	do	do	do	—	—	June	1951	4.7	650,000	—	*53	10/.120	138.5	
	do	do	do	—	—	June	1956	5.0	648,000	—	*53	10/.401	462.0	
	do	do	do	—	—	Aug.	1961	5.1	641,000	—	*53	10/1.274	1,471.0	
18-7c	Pickwick Landing	do	Pickwick, Tenn.	32,820	1,997	Feb.	1938	—	1,130,313	—	—	—	—	TVA
	do	do	do	—	—	Sept.	1946	8.6	1,116,309	—	*53	.811	936	
	do	do	do	—	—	June	1951	4.7	1,118,082	—	*53	11/-.180	—	
	do	do	do	—	—	June	1956	5.1	1,116,811	—	*53	.125	144	
	do	do	do	—	—	Aug.	1961	5.2	1,105,256	—	*53	1.113	1,285	
18-8c	Kentucky	do	Gilbertsville, Ky.	40,200	7,131	Aug.	1946	—	7/2,879,549	—	—	—	—	TVA
	do	do	do	—	—	May	1951	4.7	7/2,855,440	—	*53	.719	830	
	do	do	do	—	—	July	1956	5.2	7/2,814,388	—	*53	1.107	1,278	
	do	do	do	—	—	Oct.	1961	5.2	7/2,790,855	—	*53	.635	733	
18-9	Dale Hollow	Obey River	Celina, Tenn.	935	887	Apr.	1943	—	1,706,000	1.533	—	—	—	CE
	do	do	do	—	—	June	1960	17.2	—	—	—	—	—	
18-10	Old Hickory	Cumberland River	Old Hickory, Tenn.	12/11,674	2,741	June	1954	—	467,000	—	—	—	—	CE
	do	do	do	—	—	June	1965	11	453,703	—	—	.441	—	
18-11	Wolf Creek (Lake Cumberland)	do	Jamestown, Ky.	5,789	5,690	Aug.	1950	—	6,089,000	.912	—	—	—	CE
	do	do	do	—	—	June	1963	12.83	—	—	—	—	—	
18-12	Rough River Reservoir	Rough River	Falls of Rough, Ky.	454	437.56	Dec.	1959	—	332,940	.866	—	—	—	CE
	do	do	do	—	—	July	1969	9.75	329,670	.857	70.27	.765	1,170	
18-13	Upper Green River #5 (Pilot)	South Fork	Stanford, Ky.	1.44	1.41	Sept.	1955	—	320.71	.23	—	—	—	SCS
	do	do	do	—	—	Apr.	1966	10.5	316.99	.18	59.9	1/.26	1/339	

OHIO RIVER BASIN (POINT PLEASANT TO MADISON)
Kanawha, Big Sandy, Licking, Kentucky, Scioto, and Miami River Basins

19-1	Lake Placid	Unnamed	Lancaster, Ky.	.20	.20	Oct.	1902	—	114	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1941	38.9	95	—	—	13/2.50	—	
19-2	Radford	Little River	Radford, Va.	329	329	Aug.	1934	—	1,646	—	—	—	—	SCS
	do	do	do	—	—	July	1944	10	1,018	—	*70	.191	291	
19-3	Englewood	Stillwater	Dayton, Ohio	651	639	—	1927 14/	—	312,000	*.810	—	—	—	SCS
	do	do	do	—	—	—	1942	15	311,448	*.809	77.5	.037	63	
19-4	Germantown	Twin Creek	Germantown, Ohio	270	264	—	1927 14/	—	106,000	*.554	—	—	—	SCS
	do	do	do	—	—	—	1942	15	105,618	*.552	79.5	.097	168	
19-9b	Griggs	Scioto River	Columbus, Ohio	1,053	1,052	—	1905	—	4,563	.008	—	—	—	ODW
	do	do	do	—	—	—	1935	30	3,920	.007	*65	.020	28.3	
	do	do	do	—	—	—	1951	16	3,928	.007	59.4	—	—	
	do	do	do	—	—	—	1964	13	3,737	.007	—	.014	—	

1/ Sediment pool only.
2/ Items are based on corrected instrument surveys of shore line and range locations as used in the 1965 survey.
3/ The noncontributing drainage area is chiefly closed or plugged limestone sinkholes.
4/ In July 1925. In June 1915, spillway elevation was 5 feet lower and capacity was 1,226 ac.-ft.
5/ Revised from 228,120 to 232,370 ac.-ft.
6/ Guntersville Dam closed Jan. 19, 1939, reducing sediment contributing area to 5,033 sq. mi.
7/ Multiple-use capacity excluding diked areas.
8/ 1953 survey revised.
9/ Used drainage area below Hales Bar Dam (8,935 sq. mi.).
10/ Sediment contributing area reduced by closing Wheeler Dam, Oct. 3, 1936, to 1,135 sq. mi.
11/ Minus (-) indicates scour (treated as negative sediment).
12/ Uncontrolled drainage area 2,776 sq. mi.
13/ Including 19,000 cu. yd. dredged in 1930.
14/ Year survey ranges were established.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

OHIO RIVER BASIN (POINT PLEASANT TO MADISON)
Kanawha, Big Sandy, Licking, Kentucky, Scioto, and Miami River Basins (Continued)

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES) TOTAL	NET	DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN AC.-FT.	TONS	AGENCY SUPPLYING DATA
19-6	Ohio Cons. Pond No. 73	Blacklick Creek	Columbus, Ohio	24	24	Nov. 1936	—	4.68	--	—	—	—	SCS
	do	do	do	--	—	June 1939	2.6	2.53	--	--	0.035	--	
19-7	Ohio Cons. Pond No. 74	do	do	23	23	Jan. 1937	--	1.04	--	—	—	--	SCS
	do	do	do	—	—	Nov. 1939	2.8	.52	—	--	.008	--	
19-8a	Lake White	Pee Dee Creek	Waverly, Ohio	37.4	36.9	Oct. 1935	—	3,734	--	—	--	--	ODW
	do	do	do	—	—	Dec. 1947	12.0	3,338	--	—	0.894	—	
	do	do	do	—	—	Aug. 1951	4.0	1/3,706	—	68.0	1.73	--	
19-9	Herrington Lake	Dix River	Harrodsburg, Ky.	437	431	Oct. 1925	—	258,949	—	--	--	—	SCS
	do	do	do	--	—	Oct. 1941	16	255,706	--	--	.471	—	
19-10	Walton	Bank Lick Creek	Walton, Ky.	.25	.24	-- 1931	--	128	—	--	--	--	SCS
	do	do	do	—	—	-- 1937	6	122	—	*50	4.46	4,860	
19-11	Williamstown	Grassy Creek	Williamstown, Ky.	.47	.47	-- 1930	—	113	—	--	—	--	SCS
	do	do	do	—	—	— 1937	7	106	--	—	2.13	—	
19-12	Byllesby	New River	Byllesby, Va.	1,310	1,310	Aug. 1912	—	8,892	—	—	—	—	SCS
	do	do	do	—	—	May 1936	23.66	3,538	--	--	2/.184	--	
19-13a	O'Shaughnessy	Scioto River	Dublin, Ohio	988	987	Fall 1925	—	3/16,673	*.026	—	—	—	ODW
	do	do	do	—	—	— 1934 4/	9	15,604	*.024	*65	.121	172	
	do	do	do	—	—	— 1942 4/	8	14,538	*.023	*65	.135	191	
	do	do	do	—	—	July 1951	9	14,162	*.022	44.2	.063	60.5	
19-14a	Decker Lake	Patterson Run	Piqua, Ohio	2.33	2.30	— 1940	--	115	*.084	--	--	--	ODW
	do	do	do	—	—	June 1950	10	94	*.069	51.91	.913	1,032	
19-15b	Madison Lake	Deer Creek	London, Ohio	57.2	57.0	— 1946	—	594.0	—	--	--	--	ODW
	do	do	do	--	--	June 1949	2.6	530.2	--	49.0	.43	459	
	do	do	do	—	--	June 1951	2.0	511.0	—	45.9	.17	170	
	do	do	do	—	—	June 1954	3.0	486.7	--	49.9	.14	152	
19-16b	Grant Lake	Sterling Run	Mt. Orab, Ohio	25.25	24.97	Dec. 1948	—	1,140	.0564	--	--	—	ODW
	do	do	do	—	--	July 1950	1.6	1,111	.0550	86.6	.721	1,360	
	do	do	do	—	—	Sept. 1957	7.0	1,068	.0529	--	.247	--	
	do	do	do	--	—	Aug. 1962	5.0	1,027	.0508	--	.324	--	
	do	do	do	—	—	July 1971	9.0	965	.0478	--	.274	—	
19-17	Caldwell Lake	Trib. of Stoney Creek	Waverly, Ohio	1.02	1.00	— 1937	—	88	*.124	--	—	—	ODW
	do	do	do	—	—	Sept. 1949	12	85	*.120	*60	.253	331	
19-18	Stewart Lake	do	Chillicothe, Ohio	.31	.30	— 1939	--	74	--	--	—	--	ODW
	do	do	do	—	--	Sept. 1951	12.3	71	--	*60	.87	1,137	
19-19	Pine Lake	Tar Hollow Creek	Gillespieville, Ohio	2.42	2.40	Fall 1938	--	134	.073	--	--	—	ODW
	do	do	do	—	—	Aug. 1950	11.7	123	.067	68.95	.396	595	
19-20a	Kiser Lake	Mosquito Creek	St. Paris, Ohio	8.73	8.15	Jan. 1940	—	3,215	.575	--	—	--	ODW
	do	do	do	—	--	Jan. 1950	10.5	3,010	.539	*50	2.40	2,610	
	do	do	do	--	--	July 1954	4.0	2,929	.524	39.7	2.48	2,144	
	do	do	do	—	—	June 1962	8.0	2,867	.513	--	.95	—	
19-21	Eversole Run (Trib. arm of O'Shaughnessy Res.)	Eversole Run	Dublin, Ohio	13.8	13.7	— 1925	—	384	--	--	—	--	ODW
	do	do	do	--	—	— 1951	26	295	—	55.5	.25	302	
19-22	Allen Lake	Trib. of Silver Creek	Kenton, Ohio	.50	.50	-- 1938	—	12	*.043	--	—	--	ODW
	do	do	do	—	--	Aug. 1951	13	10	*.036	52.6	.26	298	
19-23	Sylvan Lake (Lower)	Trib. of Beaver Creek	Vienna, Ohio	1.85	1.39	— 1947	--	275	--	—	--	--	ODW
	do	do	do	—	—	Aug. 1951	3.8	261	--	44.8	2.73	2,664	
19-24	Sylvan Lake (Upper)	do	do	.40	.38	-- 1948	--	63	—	--	--	—	ODW
	do	do	do	--	—	Aug. 1951	2.8	59	—	*45	3.53	3,460	
19-25	Nostermann Lake	Trib. of Mad River	Springfield, Ohio	1.59	1.58	Nov. 1938	--	83	--	--	--	—	ODW
	do	do	do	—	—	Aug. 1951	12.7	75	--	66.2	.38	548	
19-26	Reynolds Pond	Trib. of Barren Creek	Bidwell, Ohio	.70	.70	— 1940	--	18	*.034	--	—	—	ODW
	do	do	do	—	—	Aug. 1950	10	15	*.029	57.4	.441	551	
19-27	Mt. Gilead Lake (Upper)	Sams Creek	Mt. Gilead, Ohio	8.55	5/5.50	— 1930	--	28	*.006	—	--	--	ODW
	do	do	do	--	--	Oct. 1948	18	26	*.005	*60	.039	51	
19-28	Schott Pond	Trib. of Big Walnut Creek	Westerville, Ohio	.82	.82	-- 1921	--	7.3	--	--	--	--	ODW
	do	do	do	—	--	Aug. 1951	30	4.8	--	57.1	.10	124	
19-29a	Lake Alma	Unnamed	Wellston, Ohio	.83	.70	— 1901	--	774	--	--	--	--	ODW
	do	do	do	—	—	Sept. 1951	50	744	--	55.5	.84	1,015	
19-30	Maple Grove Lake	Sams Creek	Mt. Gilead, Ohio	3.05	3.04	— 1932	—	28.1	*.014	—	--	--	ODW
	do	do	do	--	—	Sept. 1949	17	23.9	*.012	83.2	.079	143	
19-31	Pond Lick Lake	Pond Lick Run	Friendship, Ohio	2.54	2.53	— 1938	—	48	*.024	—	--	—	ODW
	do	do	do	--	--	July 1950	12.3	39	*.019	58.8	.277	355	
19-32	Wolfden Lake	Wolfden Run	do	.60	.60	— 1936	--	25.4	*.053	--	--	--	ODW
	do	do	do	—	--	July 1950	14.3	23.1	*.048	59.92	.272	355	
19-33	Bear Lake	Left Fork Bear Creek	do	.48	.47	— 1935	--	33	*.086	--	—	--	ODW
	do	do	do	—	—	July 1950	15.3	32	*.083	67.02	.196	283	
19-34	McBride Lake	Trib. of Pond Run	do	.61	.61	-- 1937	—	13	*.027	--	—	—	ODW
	do	do	do	—	—	July 1950	13.3	11	*.023	34.01	.225	167	

19-35	Roosevelt Lake	Turkey Creek	Friendship, Ohio	16.38	15.76	--	1935	--	101	*.088	--	--	--	ODW
	do	do	do	--	--	July	1950	15.3	67	*.005	61.0	.140	186	
19-36a	Adams Lake	Lick Creek	West Union, Ohio	4.45	4.39	Spring	1947	--	318	.087	--	--	--	ODW
	do	do	do	--	--	July	1950	3.5	304	.083	53.24	.895	1,098	
	do	do	do	--	--	Aug.	1960	10.0	277	.076	--	.624	--	
19-37	Vesuvius Lake	Storms Creek	Ironton, Ohio	10.9	10.7	--	1937	--	1,553	.194	--	--	--	ODW
	do	do	do	--	--	June	1949	12	1,463	.183	*54.0	.697	820	
	do	do	do	--	--	July	1952	3	1,463	.183	54.0	.019	22	
19-38	Pike Lake	Richardson Hollow of Morgan Fork	Bainbridge, Ohio	3.44	3.42	--	1937	--	6/91.4	--	--	--	--	ODW
	do	do	do	--	--	Aug.	1950	13	6/86.5	--	40.2	.11	963	
19-39	Upper Hocking No. 2	Hunters Run	Lancaster, Ohio	1.87	1.87	Apr.	1956	--	7/56.98	--	--	--	--	SCS
	do	do	do	--	--	June	1961	5.0	7/51.02	--	68.237	.637	946.711	
19-40	Jackson Lake	Black Fork River	Oak Hill, Ohio	18.8	18.4	--	1940	--	*1,700	--	--	--	--	ODW
	do	do	do	--	--	--	1951	11	*1,590	--	*60.0	.56	775	
19-41	Loramie Lake	Loramie Creek	Ft. Loramie, Ohio	78.7	77.4	--	1840	--	4,115	.099	--	--	--	ODW
	do	do	do	--	--	--	1960	120	3,115	.075	*65	.11	156	
19-42a	Sharon Woods Reservoir	Sharon Creek	Sharonville, Ohio	4.88	4.82	--	1939	--	289	--	--	--	--	ODW
	do	do	do	--	--	--	1942	2.3	274	--	*70	1.27	1,936	
	do	do	do	--	--	--	1945	3.6	232	--	*70	2.44	3,720	
	do	do	do	--	--	--	1949	4.0	206	--	*70	1.38	2,104	
19-43	Cowan Lake	Cowan Creek	Wilmington, Ohio	49.6	48.5	--	1947	--	13,305	.367	--	--	--	ODW
	do	do	do	--	--	--	1960	13	12,770	.352	*50	.847	923	
19-44	Margus Lake	Margus Creek	Circleville, Ohio	6.60	6.40	--	1956	--	2,926	.671	--	--	--	ODW
	do	do	do	--	--	--	1960	4	2,892	.663	*50	1.33	1,450	
19-45	Hillsboro	Trib. of Clear Creek	Hillsboro, Ohio	.73	.69	--	1946	--	279.9	.503	--	--	--	ODW
	do	do	do	--	--	--	1955	9	271.4	.487	*60	1.36	1,190	
19-46	Delaware	Olentangy River	Delaware, Ohio	381	379	Mar.	1951	--	132,000	.534	--	--	--	CE
	do	do	do	--	--	May	1960	9.25	8/131,483	.532	*65	8/.1475	8/208	
19-47	W. Fk. Mill Creek Reservoir (Winton Lake)	W. Fork Mill Creek	Cincinnati, Ohio	29.5	28.6	Dec.	1952	--	9/11,466	.609	--	--	--	CE
	do	do	do	--	--	May	1961	8.42	11,207	.595	71.8	1.08	1,649	
19-48	Brush Creek Reservoir	Brush Creek	Butlerville, Ind.	13.4	13.11	Dec.	1957	--	2,067.4	.183	--	--	--	SCS
	do	do	do	--	--	July	1961	9.6	1,883.0	.167	48.0	1.47	1,536.8	
19-49	Whitewater Lake	Silver Creek	Liberty, Ind.	19.29	19.0	Sept.	1954	--	3,590.0	*.249	--	--	--	SCS
	do	do	do	--	--	July	1963	8.8	3,415.6	*.237	67.5	1.04	1,529	
19-50	Jisco Lake	Trib. of Little Salt Creek	Jackson, Ohio	1.67	1.58	--	1952	--	1,109	.860	--	--	--	ODW
	do	do	do	--	--	Sept.	1968	16	1,092	.846	43.7	.67	638	
	do	do	do	--	--	Aug.	1970	2	1,088	.843	50.7	1.16	2,108	
19-51	Clark Lake	Sinking Creek	Vienna, Ohio	6.88	6.72	Late	1957	--	507.3	.106	--	--	--	ODW
	do	do	do	--	--	Sept.	1961	3.8	485.2	.102	--	.865	--	
	do	do	do	--	--	July	1968	7	456.4	.096	--	.612	--	
19-52	Acton Lake	Four Mile Creek	Oxford, Ohio	107.4	106.5	Feb.	1957	--	9,607	.134	--	--	--	ODW
	do	do	do	--	--	Aug.	1961	10/5	9,393	.131	--	.402	--	
19-53	Middle Fork Reservoir	M. Fork of E. Fork White Water Reservoir	Richmond, Ind.	48.14	47.87	Jan.	1962	--	3,250	.101	--	--	--	SCS
	do	do	do	--	--	Oct.	1967	5.5	3,040.71	.095	49.6	.79	850	
19-54	Colonial Mine Lake	Lambs Creek	Beulah, Ky.	1.05	1.00	Fall	1947	--	206.77	.227	--	--	--	SCS
	do	do	do	--	--	May	1967	20	193.93	.214	*70	.642	978.79	
19-55	"A" Strip Mine Lake	Clear Creek D.A.	Richland, Ky.	.009	.009	--	1947	--	53	3.68	--	--	--	SCS
	do	do	do	--	--	Nov.	1967	20	49.3	3.42	*80	20.56	35,824	
			TENNESSEE RIVER BASIN (ABOVE HALES BAR DAM)											
20-1b	South Holston	South Fork Holston River	Bristol, Tenn.	703	691	Nov.	1950	--	11/661,888	.905	--	--	--	TVA
	do	do	do	--	--	June	1958	7.6	660,581	.903	*55	.249	298	
	do	do	do	--	--	Aug.	1964	6.2	657,963	.900	*55	.611	732	
20-2b	Watauga	Watauga River	Hampton, Tenn.	468	458	Dec.	1948	--	11/572,600	1.159	--	--	--	TVA
	do	do	do	--	--	Mar.	1953	4.3	571,402	1.156	*55	.609	730	
	do	do	do	--	--	Apr.	1958	5.0	570,100	1.154	*55	.568	680	
	do	do	do	--	--	Aug.	1964	6.4	568,839	1.151	*55	.430	515	
20-3b	Boone	South Fork Holston River	Kingsport, Tenn.	1,840	662	Dec.	1952	--	196,668	--	--	--	--	TVA
	do	do	do	--	--	June	1958	5.5	195,633	--	*55	.284	340	
	do	do	do	--	--	Sept.	1964	6.3	193,446	--	*55	.520	623	
20-4b	Fort Patrick Henry	do	do	1,903	62	Oct.	1953	--	27,110	--	--	--	--	TVA
	do	do	do	--	--	June	1959	5.6	26,965	--	*55	.468	561	
	do	do	do	--	--	Nov.	1964	5.5	26,941	--	*55	.012	14.4	
20-5e	Cherokee	Holston River	Jefferson City, Tenn.	3,428	12/1,477	Dec.	1941	--	1,559,570	--	--	--	--	TVA
	do	do	do	--	--	Apr.	1949	7.4	1,550,932	--	*55	.340	407	
	do	do	do	--	--	Apr.	1954	5.0	1,547,776	--	*55	--	12/--	
	do	do	do	--	--	June	1959	5.1	1,545,960	--	*55	.241	289	
	do	do	do	--	--	June	1964	5.0	1,543,927	--	*55	.276	331	

1/ 1951 survey includes several additional ranges. Results of 1947 and 1951 surveys are not directly comparable.

2/ Based on total sediment in Washington Mill, Buck, Byllesby, and Fields Reservoirs; total drainage area 1,320 sq. mi.

3/ Without 3 ft. flashboards added in 1945.

4/ Survey dates: Sept.-Nov. 1934; Sept.-Dec. 1942.

5/ 1932 correction for Maple Grove.

6/ Reservoir partially dredged in March-April 1945. Data on amount of material are unreliable. Actual amounts of sediment probably 10 to 25 percent greater than indicated.

7/ Sediment pool only.

8/ Flood pool elevation 917. Ranges resurveyed to elevation 915. No appreciable sediment above elevation 915.

9/ Revised on basis of topographic maps developed for definite project report and sedimentation range data.

10/ 1957 water year included.

11/ Multiple-use storage capacity. Reservoir has greater capacity at spillway crest elevation.

12/ Sediment contributing area reduced from 3,381 sq.mi. to 1,477 sq. mi. by closing of Watauga Dam Dec. 1, 1948; South Holston on Nov. 27, 1950; Boone on Dec. 16, 1952; and Fort Patrick Henry on Oct. 27, 1953. Area above Watauga included in 1949 survey as sediment contributing area.

* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
						TENNESSEE RIVER BASIN (ABOVE HALES BAR DAM) (Continued							
20-6d	Nolichucky	Nolichucky River	Greenville, Tenn.	1,183	1,182	Fall 1913	--	1/[illegible],100	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Fall 1925	12	2/21,750	.017	--	--	--	
	-----do-----	-----do-----	-----do-----	--	--	Feb. 1938	12.5	14,450	.011	50	0.252	274	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1947	9.2	12,010	.009	*50	.224	245	
	-----do-----	-----do-----	-----do-----	--	--	May 1953	6.1	9,850	.008	*50	.299	326	
	-----do-----	-----do-----	-----do-----	--	--	Oct. 1958	5.4	7,760	.006	*50	.327	357	
	-----do-----	-----do-----	-----do-----	--	--	Feb. 1962	3.3	7,470	.006	*50	.107	117	
	-----do-----	-----do-----	-----do-----	--	--	Mar. 1967	6.1	2/3,325	.003	*50	.075	82	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1970	3.5	2,630	.002	*50	.168	183	
20-7c	Douglas	French Broad River	Sevierville, Tenn.	4,541	2,954	Feb. 1943	--	3/1,511,883	.312	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	July 1949	6.4	1,496,712	.308	*55	.830	994	
	-----do-----	-----do-----	-----do-----	--	--	May 1955	5.8	1,500,870	.309	*55	4/-.251	--	
	-----do-----	-----do-----	-----do-----	--	--	June 1960	5.1	1,489,978	.307	*55	.748	895	
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1967	7.2	1,475,450	.304	*55	.707	847	
20-8c	Fort Loudoun	Tennessee River	Lenoir City, Tenn.	9,550	1,556	Nov. 1946	--	400,945	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	June 1951	4.6	399,414	--	*55	.214	256	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1956	4.8	398,060	--	*55	.181	217	
	-----do-----	-----do-----	-----do-----	--	--	May 1961	5.1	392,711	--	*55	.674	807	
20-9b	Thorpe	W. Fk. Tuckasegee River	Glenville, N. C.	36.7	34.4	Feb. 1941	--	--	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	9.6	3/70,700	.888	--	--	--	
	-----do-----	-----do-----	-----do-----	--	--	July 1958	7.8	70,537	.886	*55	.61	731	
	-----do-----	-----do-----	-----do-----	--	--	May 1969	10.9	70,487	.882	*55	.13	160	
20-10b	Nantahala	Nantahala River	Aquone, N. C.	91	88	Sept. 1950	--	138,083	.561	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	July 1958	7.9	137,882	.560	*55	.284	340	
	-----do-----	-----do-----	-----do-----	--	--	May 1969	10.8	137,159	.570	*55	.761	912	
20-11c	Fontana	Little Tennessee River	Fontana, N. C.	1,571	1,436	Nov. 1944	--	3/1,455,062	.543	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Mar. 1950	5.4	1,452,385	.534	*55	.348	416.9	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1954	4.5	1,450,646	.534	*55	.271	324.6	
	-----do-----	-----do-----	-----do-----	--	--	June 1959	4.7	1,448,311	.533	*55	.349	418.1	
	-----do-----	-----do-----	-----do-----	--	--	Oct. 1967	8.3	1,443,262	.531	*55	.426	511	
20-12	Cheoah	-----do-----	Tapoco, N. C.	1,608	1,607	Dec. 1918	--	2/44,0[illegible]0	.016	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1930	11.8	39,030	.014	*55	.264	316	
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1941	10.9	5/35,030	.013	--	.228	273	
20-13b	Caryville	Cove Creek	Caryville, Tenn.	35.98	35.[illegible]	Nov. 1936	--	4/1,726	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Nov. 1938	2.0	1,652	--	62	1.038	1,401.7	
	-----do-----	-----do-----	-----do-----	--	--	Jan. 1947	8.2	1,580	--	*62	.250	337.6	
	-----do-----	-----do-----	-----do-----	--	--	Mar. 1954	7.1	1,347	--	*62	.917	1,238.3	
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1960	6.4	1,290	--	*62	.250	337.6	
	-----do-----	-----do-----	-----do-----	--	--	July 1970	9.9	1,118	--	*62	.488	658	
20-14c	Norris	Clinch River	Norris, Tenn.	[illegible]	[illegible]	Mar. 1936	--	1/7/2,061,569	.692	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	June 1946	10.3	2,052,357	.691	*55	.317	379.7	
	-----do-----	-----do-----	-----do-----	--	--	June 1954	8.0	2,047,527	.690	*55	.214	256.2	
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1960	6.1	2,044,768	.689	*55	.160	191.7	
	-----do-----	-----do-----	-----do-----	--	--	June 1970	9.8	2,036,324	.684	*55	.305	366	
20-15c	Watts Bar	Tennessee River	Spring City, Tenn.	[illegible]	[illegible]	Oct. 1946	--	1,195,229	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	June 1951	4.7	1,193,106	--	*55	.155	186	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1956	4.8	1,183,735	--	*55	.667	799	
	-----do-----	-----do-----	-----do-----	--	--	June 1961	5.1	1,174,954	--	*55	.589	706	
20-16b	Chatuge	Hiwassee River	Hayesville, N. C.	189	189	Feb. 1942	--	242,325	.705	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1949	7.5	242,032	.704	*55	.219	262.3	
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1954	5.0	241,502	.702	*55	.595	712.8	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1960	6.0	240,999	.701	*55	.472	565.4	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1965	4.6	240,516	.699	*55	.590	707.0	
20-17b	Nottely	Nottely River	Blairsville, Ga.	214	207	Jan. 1942	--	3/176,521	.586	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1949	7.6	175,865	.584	*55	.415	497.1	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1955	5.7	174,969	.581	*55	.758	908.0	
	-----do-----	-----do-----	-----do-----	--	--	May 1961	6.0	174,429	.579	*55	.435	521.0	
	-----do-----	-----do-----	-----do-----	--	--	Apr. 1965	4.0	174,357	.579	*55	.087	104.0	
20-18b	Hiwassee	Hiwassee River	Murphy, N. C.	968	8/539	Feb. 1940	--	3/439,742	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1947	7.5	436,009	--	*55	8/--	8/--	
	-----do-----	-----do-----	-----do-----	--	--	May 1953	5.8	435,686	--	*55	.1[illegible]4	125	
	-----do-----	-----do-----	-----do-----	--	--	June 1958	5.0	434,243	--	*55	.536	642	
	-----do-----	-----do-----	-----do-----	--	--	May 1965	6.9	433,568	--	*55	.182	218	
20-19c	Apalachia	-----do-----	Farner, Tenn.	1,018	48	Feb. 1943	--	58,312	--	--	--	--	TVA
	-----do-----	-----do-----	-----do-----	--	--	Aug. 1950	7.5	57,979	--	*55	.938	1,124	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1960	10.1	57,550	--	*55	.883	1,058	
	-----do-----	-----do-----	-----do-----	--	--	May 1965	4.7	57,753	--	*55	4/--	--	

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20-20c	Blue Ridge	Toccoa River	Blue Ridge, Ga.	232	227	Apr.	1944	—	197,427	.462	—	—	—	TVA
	do	do	do	—	—	Aug.	1949	5.3	196,080	.454	*55	1.119	1,340.5	
	do	do	do	—	—	Aug.	1954	5.0	195,981	.454	*55	.881	1,055.35	
	do	do	do	—	—	June	1959	4.8	196,522	.455	*55	4/-.498	—	
	do	do	do	—	—	Apr.	1968	8.8	195,908	.454	*55	.308	368	
20-21d	Ocoee No. 3	Ocoee River	Ducktown, Tenn.	496	263	Aug.	1942	—	14,304	.017	—	—	—	TVA
	do	do	do	—	—	July	1945	2.9	12,140	—	*64	9/2.114	9/2,947	
	do	do	do	—	—	Nov.	1946	1.3	11,349	—	*64	2.312	3,223	
	do	do	do	—	—	Aug.	1948	1.8	10,570	—	64	1.646	2,294	
	do	do	do	—	—	Aug.	1950	2.0	9,849	—	*64	1.373	1,914	
	do	do	do	—	—	July	1953	3.0	8,696	—	*64	1.460	2,035	
	do	do	do	—	—	Oct.	1955	2.1	8,042	—	*64	1.183	1,649	
	do	do	do	—	—	Oct.	1958	3.0	6,766	—	*64	1.616	2,253	
	do	do	do	—	—	Oct.	1960	2.0	5,920	—	*64	1.608	2,242	
	do	do	do	—	—	June	1962	1.8	5,286	—	*64	1.388	1,865	
	do	do	do	—	—	Sept.	1965	3.2	4,653	—	*64	.753	1,050	
	do	do	do	—	—	Mar.	1968	2.6	4,026	.005	*64	.916	1,278	
20-22d	Ocoee No. 1	do	Parksville, Tenn.	595	10/96	Dec.	1911	—	11/109,200	—	—	—	—	TVA
	do	do	do	—	—	Oct.	1940	28.8	12/91,300	—	*64	—	—	
	do	do	do	—	—	Sept.	1949	8.9	13/86,737	—	64	—	—	
	do	do	do	—	—	Aug.	1954	5.0	87,267	—	*64	4/-1.10	—	
	do	do	do	—	—	June	1959	4.9	86,809	—	*64	.974	1,358	
	do	do	do	—	—	Apr.	1968	8.8	86,466	.091	*64	.406	566	
20-23c	Chickamauga	Tennessee River	Chattanooga, Tenn.	20,790	14/1,805	Nov.	1940	—	746,951	—	—	—	—	TVA
	do	do	do	—	—	July	1947	6.7	734,970	—	*60	14/—	14/—	
	do	do	do	—	—	Aug.	1954	7.0	745,178	—	*60	4/-0.808	—	
	do	do	do	—	—	May	1956	1.8	740,367	—	*60	1.481	1,935	
	do	do	do	—	—	June	1961	5.1	738,820	—	*60	.168	220	
20-24d	Hales Bar	do	Jasper, Tenn.	21,790	15/990	Oct.	1935	—	153,483	—	—	—	—	TVA
	do	do	do	—	—	Oct.	1940	5.0	152,928	—	61	15/—	—	
	do	do	do	—	—	July	1947	6.7	152,251	—	*61	.102	135	
	do	do	do	—	—	Aug.	1954	7.1	152,992	—	*61	4/-.105	—	
	do	do	do	—	—	May	1956	1.8	153,032	—	*61	4/-.022	—	
	do	do	do	—	—	June	1961	5.1	154,002	—	*61	4/-.192	—	
	do	do	do	—	—	Dec.	1967	6.5	154,012	.0056	—	4/-	—	
20-25	Kanuga Lake	Little Mud Creek	Hendersonville, N. C.	1.54	1.50	—	1908	—	16/246	.120	—	—	—	SCS
	do	do	do	—	—	Oct.	1956	48	190	.093	43.1	.780	732	
20-26	Osceola Lake	Shepard Creek	do	4.45	4.39	—	1923	—	16/329	.055	—	—	—	SCS
	do	do	do	—	—	Oct.	1956	33	267	.045	45.7	.428	426	
20-27	Melton Hill	Clinch River	Clinton, Tenn.	3,343	422	July	1963	—	125,900	.0429	—	—	—	TVA
	do	do	do	—	—	May	1970	7	125,578	.0428	*55	.109	131	
20-28	Upper Ollie Creek Reservoir	Ollie Creek	La Follette, Tenn.	10.8	10.75	Apr.	1964	—	561	.051	—	—	—	TVA
	do	do	do	—	—	Oct.	1970	6.5	649	.090	*62	.172	232	
OHIO RIVER BASIN (ABOVE POINT PLEASANT, AND LAKE ERIE DRAINAGE														
21-1	Pleasant Hill	Clear Fork	Perrysville, Ohio	199	195	Oct.	1938	—	87,700	.676	—	—	—	CE
	do	do	do	—	—	Feb.	1945	6.25	87,424	.674	*65	.227	321	
21-2a	Senecaville	Seneca Fork	Senecaville, Ohio	121	113	Oct.	1936 17/	—	88,500	.962	—	—	—	CE
	do	do	do	—	—	Mar.	1945	8.3	87,667	.953	*65	.89	1,260	
21-3a	Charles Mill	Black Fork, Mohican River	Mansfield, Ohio	216	207	June	1938	—	88,000	*.657	—	—	—	CE
	do	do	do	—	—	Sept.	1946	8.25	85,886	*.641	*65	1.24	1,755	
	do	do	do	—	—	July	1954	7.75	85,483	*.638	*65	.253	358	
21-4	Hinckston Run	Hinckston Run	Johnstown, Pa.	10.75	10.57	—	1905	—	3,453	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1937	32	3,315	—	*60	.408	533	
21-5	Quemahoning	Quemahoning Creek	do	92	90.7	Jan.	1912	—	35,295	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1937	25.8	34,413	—	—	.377	—	
21-6	Salt Lick	Salt Lick Run	do	11.86	11.76	—	1914	—	2,492	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1937	23	2,432	—	*60	.22	287	
21-7a	Bridgeport (Upper)	Jacobs Creek	Mt. Pleasant, Pa.	18/31.64	18/31.52	Mar.	1887	—	642.0	.016	—	—	—	SCS
	do	do	do	—	—	Nov.	1937	50.6	453.0	.011	—	18/.118	168	
	do	do	do	—	—	Nov.	1964	27.0	338.5	.008	65.4	.134	191	

1/ Prior to 1925 dam was 35 ft. lower.
2/ Original volume computed from probings obtained Feb. 1938. Sediment deposits and water inflow computed from dam closure in 1913. Five foot flash boards removed Sept. 1964.
3/ Revised.
4/ Minus (-) indicates scour. Treated as negative sediment.
5/ Computed from probings and available maps.
6/ From first accurate area-volume curves, 1941 conditions.
7/ Multiple-use storage capacity. Reservoir has greater capacity at spillway crest elevation.
8/ Nottely Dam closed Jan. 24, 1942. Chatuge Dam closed Feb. 12, 1942.
9/ Does not include 553 ac.-ft. of sediment flushed into reservoir when small upstream dam failed in Mar. 1944.
10/ Blue Ridge Reservoir closed Dec. 5, 1930. Ocoee #3 closed Aug. 15, 1942.
11/ Based on Tenn. Electric Power Co. data adjusted to latest topographic maps.
12/ Volume computed by average end area method from first accurate area-volume curves - 1940 conditions.
13/ Volume computed from contours based on 1949 survey.
14/ Sediment contributing area reduced by closing Watts Bar Dam on Jan. 1, 1942, and Apalachia Dam, Feb. 14, 1943.
15/ Norris Dam closed Mar. 4, 1936, and Chickamauga Dam closed Jan. 15, 1940, reducing sediment contributing area to 990 sq. mi.
16/ Determined during 1956 survey.
17/ Date storage began. Sediment ranges established and surveyed in Dec. 1937 by Soil Conservation Service, USDA.
18/ Original data revised. 1964 survey data based on corrected elevation and topography from transit survey (1963).
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
						OHIO RIVER BASIN (ABOVE POINT PLEASANT) AND LAKE ERIE DRAINAGE (Continued)							
21-8	Barberton	Wolf Creek	Barberton, Ohio	28.2	28.0	-- 1926	--	2,056	*.101	--	--	--	SCS
	do	do	do	--	--	Dec. 1938	12	1,688	*.083	*55	1.10	1,320	
21-9	Buckeye Lake	S. Fork Licking River	Millersport, Ohio	1/49.2	45.1	-- 1832	--	2/19,960	--	--	--	--	SCS
	do	do	do	--	--	July 1939	107	15,790	--	*50	.860	937	
21-10	Leesville	McGuire Creek	Leesville, Ohio	48.0	45.7	Aug. 1936	--	37,400	*1.159	--	--	--	SCS
	do	do	do	--	--	Nov. 1939	3.3	37,390	*1.159	*50	.067	73	
21-11	Muskingum College	Trib. of Muskingum River	New Concord, Ohio	.32	.31	-- 1915	--	9.41	*.042	--	--	--	SCS
	do	do	do	--	--	Nov. 1935	20	7.05	*.031	*70	.381	581	
21-12	Ohio Cons. Pond No. 22	Trib. of Duck Creek	Marietta, Ohio	.05	.05	Oct. 1938	--	4.43	*.116	--	--	--	SCS
	do	do	do	--	--	Nov. 1939	1.1	4.21	*.110	*40	4.00	3,485	
21-13	Ohio Cons. Pond No. 51	Trib. of Ohio River	do	.13	.13	Oct. 1938	--	15.16	*.152	--	--	--	SCS
	do	do	do	--	--	Nov. 1939	1.1	15.02	*.151	*40	.977	851	
21-14	Ohio Cons. Pond No. 52	do	do	.17	.16	-- 1928	--	17.95	*.138	--	--	--	SCS
	do	do	do	--	--	Nov. 1939	11	15.40	*.118	*50	1.45	1,579	
21-15	Robbins Lake	Ford Creek	Hartford, Ohio	4.47	4.45	Summer 1922	--	91.6	*.028	--	--	--	SCS
	do	do	do	--	--	Dec. 1939	17.4	79.9	*.025	*68	.151	224	
21-16	Gorleys Lake	Trib. of Youghiogheny R.	Uniontown, Pa.	3.00	2.97	-- 1908	--	150	--	--	--	--	SCS
	do	do	do	--	--	June 1939	30	138	--	*60	.135	176	
21-17	Lake Rockwell	Cuyahoga River	Kent, Ohio	205.5	3/124.1	Aug. 1914	--	7,423	--	--	--	--	SCS
	do	do	do	--	--	Aug. 1950	36	6,887	--	46	.120	120	
21-18a	Stony Lake	McGuire Creek	Perrysville, Ohio	11.75	11.72	-- 1927	--	121	--	--	--	--	ODW
	do	do	do	--	--	Dec. 1938	11.0	80	--	*65	.319	452	
	do	do	do	--	--	May 1949	10.4	61	--	*65	.156	221	
21-19	Tabor Club Lake	Small Br. Muskingum River	do	.55	.54	-- 1923	--	53.6	*.145	--	--	--	SCS
	do	do	do	--	--	Dec. 1938	15	42.4	*.115	*40	4/1.38	1,200	
21-20	Zanesville Nursery Lake	N. Br. Blount Run	Zanesville, Ohio	2.95	2.93	Dec. 1936	--	76.62	*.034	--	--	--	SCS
	do	do	do	--	--	July 1941	4.6	72.23	*.032	*65	.326	462	
21-21a	Tionesta	Tionesta Creek	Tionesta, Pa.	478	474	Feb. 1941	--	133,400	.210	--	--	--	CE
	do	do	do	--	--	Sept. 1949	8.6	132,571	.209	*65	.203	287	
21-22b	Loyalhanna	Loyalhanna Creek	Saltsburg, Pa.	290	285	June 1942	--	5/95,300	.278	--	--	--	CE
	do	do	do	--	--	Oct. 1948	6.33	94,652	.276	*44	.358	343	
	do	do	do	--	--	Sept. 1953	4.92	94,192	.275	44	.326	312	
	do	do	do	--	--	Apr. 1962	8.58	93,501	.273	*44	.284	272	
21-23b	Mahoning Creek	Mahoning Creek	Dayton, Pa.	340	336	June 1941	--	6/74,200	.180	--	--	--	CE
	do	do	do	--	--	Aug. 1948	7.2	73,807	.172	*65	.162	229	
	do	do	do	--	--	June 1965	16.8	72,800	.177	43	.178	167	
21-24b	Crooked Creek	Crooked Creek	Ford City, Pa.	277	274	Apr. 1940	--	7/93,900	.307	--	--	--	CE
	do	do	do	--	--	Sept. 1945	5.4	93,808	.307	*65	.062	87.8	
	do	do	do	--	--	Aug. 1964	18.9	92,376	.302	51	.277	308	
21-25a	Tygart River	Tygart River	Grafton, W. Va.	1,184	1,179	Oct. 1937	--	289,600	.175	--	--	--	CE
	do	do	do	--	--	Feb. 1945 8/	--	--	--	--	--	--	
	do	do	do	--	--	Mar. 1959	21.5	287,700	.174	*65	.075	106	
21-26a	Youghiogheny River	Youghiogheny River	Confluence, Pa.	434	428	Oct. 1943	--	254,000	.406	--	--	--	CE
	do	do	do	--	--	Oct. 1949	6.0	253,121	.405	*65	.341	483	
21-27a	Atwood Reservoir	Indian Fk., Conotton Creek	Sherrodsville, Ohio	70	66.2	Apr. 1940	--	49,700	.994	--	--	--	CE
	do	do	do	--	--	Dec. 1946	6.7	49,570	.991	*65	.29	410	
21-28	Babb Pond	Unnamed	Richfield, Ohio	.02	.02	-- 1932	--	.245	*.019	--	--	--	SCS
	do	do	do	--	--	Apr. 1951	19	.189	*.015	*60	.15	196	
21-29	Basom Pond	do	Hudson, Ohio	.32	.32	-- 1944	--	3.87	*.019	--	--	--	SCS
	do	do	do	--	--	Apr. 1951	7	3.24	*.016	*60	.281	367	
21-30	Christener Pond	do	Parma, Ohio	.09	.09	-- 1940	--	3.40	*.058	--	--	--	SCS
	do	do	do	--	--	Apr. 1951	11	2.79	*.048	*60	.611	798	
21-31	Schoenbeck Pond	do	Richfield, Ohio	.03	.03	-- 1940	--	1.48	*.076	--	--	--	SCS
	do	do	do	--	--	Apr. 1951	11	1.29	*.066	*60	.567	741	
21-32	Ticky Pond	do	Peninsula, Ohio	.16	.16	-- 1949	--	2.84	*.027	--	--	--	SCS
	do	do	do	--	--	Apr. 1951	2	2.81	*.027	*60	.100	131	
21-33b	Lake Hope	Sandy Run	Zaleski, Ohio	9.95	9.75	May 1939	--	1,555	.201	--	--	--	ODW
	do	do	do	--	--	July 1949	10.2	1,511	.195	74.8	.442	720	
	do	do	do	--	--	June 1955	5.9	1,481	.191	--	.523	--	
	do	do	do	--	--	Aug. 1969	14.2	1,451	.187	--	.213	--	
21-34b	Jefferson Lake	Town Fk. Yellow River	Richmond, Ohio	7.52	7.48	Dec. 1935	--	178	.029	--	--	--	ODW
	do	do	do	--	--	Aug. 1950	15	156	.025	37.9	.199	164	
	do	do	do	--	--	June 1956	6	134	.022	--	.466	--	
	do	do	do	--	--	June 1961	5	131	.021	--	.078	--	

21-35a	Clouse Lake	Otr. Br. Rush Creek	Somerset, Ohio	8.7	8.66	—	1948	—	234	.037	—	—	—	ODW
	do	do	do	—	—	—	1949	2.0	217	.035	9/55.7	1.00	10/1,213	
	do	do	do	—	—	—	1950	1.0	206	.033	9/50.6	1.27	1,177	
	do	do	do	—	—	—	1951	1.0	202	.032	*9/53	.45	693	
	do	do	do	—	—	—	1952	1.0	199	.032	9/55.6	.34	609	
	do	do	do	—	—	—	1953	1.0	197	.031	9/65.3	.25	1,239	
	do	do	do	—	—	—	1954	1.0	193	.031	9/68.2	.41	926	
	do	do	do	—	—	—	1955	1.0	192	.031	—	.14	—	
	do	do	do	—	—	—	1956	1.0	187	.030	—	.55	—	
	do	do	do	—	—	—	1957	1.0	183	.029	—	.47	—	
	do	do	do	—	—	—	1958	1.0	177	.028	—	.64	—	
	do	do	do	—	—	—	1959	1.0	176	.028	—	.18	—	
	do	do	do	—	—	—	1961	2.0	170	.027	—	.37	—	
	do	do	do	—	—	—	1962	1.0	166	.026	—	.42	—	
	do	do	do	—	—	—	1963	1.0	163	.026	—	.33	—	
	do	do	do	—	—	—	1964	1.0	159	.025	—	.45	—	
	do	do	do	—	—	—	1966	2.0	150	.024	—	.55	—	
	do	do	do	—	—	—	1967	1.0	148	.024	—	.22	—	
	do	do	do	—	—	—	1968	1.0	146	.023	—	.236	—	
	do	do	do	—	—	—	1969	1.0	145	.023	—	.136	—	
	do	do	do	—	—	—	1970	1.0	142	.023	—	.319	—	
21-36	East Branch	E. Br. Cuyahoga River	Burton, Ohio	17.53	16.88	—	1939	—	4,659	*.340	—	—	—	ODW
	do	do	do	—	—	June	1949	9.7	4,535	*.331	*60	.759	661	
21-37	Westville Lake	Trib. of Mahoning River	Alliance, Ohio	8.36	8.22	—	1913	—	994	—	—	—	—	ODW
	do	do	do	—	—	Aug.	1950	37	933	—	66	.20	287	
21-38	Berlin	Mahoning River	Berlin Center, Ohio	249	246	July	1943	—	—	—	—	—	—	CE
	do	do	do	—	—	Nov.	1951	8.4	91,200	.551	*100	1.30	2,830	
21-39a	Mountain Lake	Broad Ford Run	Mt. Lake Park, Md.	7.4	7.4	—	1880*	—	122.75	—	—	—	—	SCS
	do	do	do	—	—	July	1957	76	77.02	—	—	.081	—	
21-40	Blaser Lake	Trib. of Sandy Creek	Minerva, Ohio	.07	.07	—	1931	—	.15	—	—	—	—	ODW
	do	do	do	—	—	—	1938	7	.0	—	*65	.29	410	
21-41	Braden Lake	do	do	.12	.12	—	1930	—	.11	—	—	—	—	ODW
	do	do	do	—	—	—	1938	8	.00	—	65	.08	113.3	
21-42	Lake Milton	Mahoning River	Milton, Ohio	280	277.4	—	1916	—	28,100	—	—	—	—	ODW
	do	do	do	—	—	—	1941	25	22,290	—	*65	.84	1,189	
21-43	Peters Pond	Trib. of Indian Creek	Lancaster, Ohio	.11	.11	—	1946	—	9.46	—	—	—	—	ODW
	do	do	do	—	—	—	1954	8	9.11	—	68.1	.36	377	
21-44	Wyandot Lake	Trib. of Clear Creek	Logan, Ohio	.58	.58	—	1930	—	11.5	—	—	—	—	ODW
	do	do	do	—	—	—	1948	18	4.65	—	—	.657	—	
21-45	Orchard Park	Pipe Creek	Orchard Park, N. Y.	1.67	—	—	1928	—	169.99	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1951	23	161.26	—	*60	.23	300	
21-46	Terra Alta Lake	Snowy River	Kingwood, W. Va.	4.76	—	—	1902	—	144.8	—	—	—	—	SCS
	do	do	do	—	—	June	1952	50	117.3	—	*50	.117	127	
21-47	Centerville Mills Lake	Aurora Br. Chargrin River	Aurora, Ohio	10.4	10.38	—	1855	—	86.3	.010	—	—	—	ODW
	do	do	do	—	—	—	1949	94	38.3	.004	*65	.0493	69.6	
21-48	Meander Creek	Meander Creek	Youngstown, Ohio	84.9	81.76	—	1929	—	32,600	.597	—	—	—	ODW
	do	do	do	—	—	—	1949	20	31,835	.586	*65	.346	489	
21-49	Havard Mason	Salem Fork	Salem, W. Va.	.29	.29	Oct.	1954	—	69.58	.265	—	—	—	SCS
	do	do	do	—	—	Oct.	1956	2.0	68.95	.262	*60	1.09	1,424.4	
	do	do	do	—	—	Oct.	1958	2.0	68.77	.261	—	.31	405.1	
	do	do	do	—	—	Dec.	1960	2.2	68.60	.261	—	.27	352.8	
21-50	Knox Lake	E. Branch Kokosing	Fredericktown, Ohio	31.4	30.66	11/Fall	1949	—	3,502	.146	—	—	—	ODW
	do	do	do	—	—	Aug.	1960	7	3,399	.142	—	.48	—	
	do	do	do	—	—	July	1970	10	3,283	.137	—	.378	—	
21-51	Veto Lake	Little Hocking River	Belpre, Ohio	20.04	19.79	May	1954	—	1,111	.0642	—	—	—	ODW
	do	do	do	—	—	July	1955	1.2	1,092	.0631	—	.787	—	
	do	do	do	—	—	July	1960	5	1,059	.0612	—	.341	—	
	do	do	do	—	—	Aug.	1966	6	1,009	.0583	—	.419	—	
21-52	Clear Fork Reservoir	Clear Fork	Lexington, Ohio	33.63	32.05	Oct.	1948	—	13,176	.565	—	—	—	ODW
	do	do	do	—	—	Aug.	1956	8	12,886	.553	—	1.13	—	
	do	do	do	—	—	July	1962	6	12,731	.546	—	.806	—	
21-53	Findley Lake	Wellington Creek	Wellington, Ohio	6.25	6.12	Mar.	1956	—	760.4	.190	—	—	—	ODW
	do	do	do	—	—	June	1961	5.6	745.5	.186	—	.435	—	
21-54	Lake Logan	Clear Fork	Logan, Ohio	14.7	14.17	Feb.	1955	—	3,142	.291	—	—	—	ODW
	do	do	do	—	—	Aug.	1966	11.8	3,081	.285	—	.363	—	
21-55	Ischua Creek Site #2	Johnson Creek	Franklinville, N. Y.	2.8	2.75	Aug.	1964	—	465	.156	—	—	—	SCS
	do	do	do	—	—	July	1967	2.91	464.72	.156	*80	.0345	60.5	
	do	do	do	—	—	Sept.	1969	2.16	464.33	.156	80	.0665	116	
21-56	Ischua Creek Site #5	Gates Creek	do	6.4	6.28	Aug.	1964	—	1,085	.159	—	—	—	SCS
	do	do	do	—	—	Aug.	1967	3	1,083.77	.159	*80	.065	113.3	
	do	do	do	—	—	Sept.	1969	2.12	1,082.95	.159	80	.062	108	

1/ Drainage area has been 115 sq. mi. (net) part of the time in the past, when fed partly by feeder from S. Fork Kirkerville River.

2/ At present spillway elevation (lowered in 1908). From 1836 to 1908, spillway elevation was 893.4, surface area 3,636 acres, and capacity 22,090 ac.-ft. From 1832 to 1836, spillway elevation was lower and surface area was 3,136 acres. Natural lake of 650 acres originally.

3/ East Branch Reservoir and many natural lakes act as efficient sediment traps.

4/ Dam failed earlier in 1938 but little sediment lost.

5/ At elevation 975. Elevation top of gates = 976 ft.

6/ At elevation 1,162. Elevation top of gates = 1,164 ft.

7/ At elevation 920. Spillway crest elevation = 918 ft.

8/ In view of the limited amount of sediment computed in the 1945 report (384 ac.-ft.), the values of the 1945 report are not included and were not used in computing survey data for the 1959 report. It is considered that the longer period (21.5 yr.) was necessary to develop a volume capable of being measured with a reasonable degree of accuracy.

9/ Density for entire period of record.

10/ Computed from differences in total sediment accumulation in tons at each survey.

11/ Gate closed Fall 1949. Drained March 1950. Gate closed May 1954.

* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	OHIO RIVER BASIN (ABOVE POINT PLEASANT) AND LAKE ERIE DRAINAGE (Continued)												
21-47	North Fk. Cowanesque River (PA-406)	White Branch	North Fork, Pa.	3.4	3.3	Aug. 1962	--	654.13	.21	--	--	--	SCS
	do	do	do	--	--	July 1967	4.9	653.89	.21	71	1/0.015	1/23.2	
21-48	Salem Fork No. 11A	Varner Hollow	Salem, W. Va.	.288	.287	Oct. 1954	--	53	.168	--	--	--	SCS
	do	do	do	--	--	Oct. 1956	2	52.25	.166	*60	1.307	1,708	
	do	do	do	--	--	Oct. 1958	2	52.05	.165	--	.348	455	
	do	do	do	--	--	Dec. 1960	2.17	51.95	.165	--	.16	209	
	do	do	do	--	--	June 1962	1.58	51.75	.164	--	.443	579	
21-49	Upper Hocking No. 1	Hunters Run	Lancaster, Ohio	1.04	.96	Apr. 1956	--	450	.882	--	--	--	SCS
	do	do	do	--	--	June 1962	6.08	446.13	.875	71.6	.678	1,057	
	GREAT LAKES DRAINAGE (IN MICHIGAN) AND MAUMEE RIVER BASIN												
22-1	Grand2/	St. Marys and Wabash River	Celina, Ohio	119	93	-- 1844	--	3/130,175	*2.193	--	--	--	SCS
	do	do	do	--	--	Aug. 1940	96	106,605	*1.796	*55	2.64	3,162	
22-2	Stronach	Pine R. of Manistee River	Wellston, Mich.	291	233	-- 1912	--	640	*.003	--	--	--	SCS
	do	do	do	--	--	Jan. 1953	41	27	*.0001	110.4	.064	154	
22-3	Goller Pond	Unnamed	Defiance, Ohio	.026	.024	Mar. 1945	--	9.5	*.761	--	--	--	ODW
	do	do	do	--	--	Aug. 1951	6.4	9.4	*.753	*45	.92	902	
22-4	Auglaize R. Power	Auglaize River	do	2,329	2,326	-- 1912	--	3/14,400	.012	--	--	--	ODW
	do	do	do	--	--	-- 1951	39	11,600	.009	--	.031	--	
22-5	Eagle Creek5/	Eagle Creek	do	5.23	5.20	-- 1912	--	129	.050	--	--	--	ODW
	do	do	do	--	--	July 1951	39	74	.029	59	.27	347	
22-6	Beetree Creek5/	Beetree Creek	do	1.94	1.91	-- 1912	--	148	*.156	--	--	--	ODW
	do	do	do	--	--	Aug. 1951	39	104	*.109	52.5	.59	675	
22-7	Batt Pond	Unnamed	do	.013	.012	Apr. 1947	--	2.7	*.417	--	--	--	ODW
	do	do	do	--	--	July 1951	4.3	2.5	*.401	73.4	2.75	4,396	
22-8	Harrison Lake	Mill Creek	Fayette, Ohio	37.2	37.0	-- 1941	--	991	.051	--	--	--	ODW
	do	do	do	--	--	June 1949	8.3	929.1	.048	53.2	.20	232	
	do	do	do	--	--	July 1951	2.1	902.4	.046	*53	.34	392	
22-9	Allmandinger Pond	Unnamed	Ohio City, Ohio	.038	.035	Jan. 1945	--	5.08	*.239	--	--	--	ODW
	do	do	do	--	--	July 1951	6.7	4.71	*.221	53.7	1.71	2,001	
22-10	Bucyrus No. 2	Trib. of Sandusky River	Bucyrus, Ohio	2.84	2.79	-- 1919	--	242	.120	--	--	--	ODW
	do	do	do	--	--	June 1949	30	218	.108	45.4	.28	277	
22-11c	Gentris Pond6/	Trib. of Hoo Creek	Lafayette, Ohio	.13	.13	-- 1947	--	9.2	.133	--	--	--	ODW
	do	do	do	--	--	-- 1951	4	7.9	.114	57.8	2.60	3,270	
	do	do	do	--	--	-- 1954	3	7.4	.107	*49.3	1.36	1,460	
	do	do	do	--	--	-- 1962	8	6.3	.091	--	.969	--	
22-12	Sixmile Creek5/	Sixmile Creek	Defiance, Ohio	21.6	21.4	-- 1912	--	995	*.094	--	--	--	ODW
	do	do	do	--	--	July 1951	39	696	*.066	43.8	.36	343	
22-13a	Burt Lake	Unnamed	Oakwood, Ohio	.76	.74	Sept. 1948	--	59	*.155	--	--	--	ODW
	do	do	do	--	--	July 1951	2.8	57	*.150	37.2	1.13	924	
22-14	Kohart Pond	Unnamed	Grover Hill, Ohio	.021	.019	Sept. 1943	--	2.4	*.229	--	--	--	ODW
	do	do	do	--	--	July 1951	7.8	2.3	*.219	26.1	.53	301	
22-15	Van Buren Lake	Rocky Ford Creek	Findlay, Ohio	22.80	22.72	Spring 1939	--	248	.022	--	--	--	ODW
	do	do	do	--	--	Nov. 1948	9.5	205	.019	53.6	.20	233	
	do	do	do	--	--	Aug. 1951	2.8	186	.017	57.9	.31	391	
22-16	Norvell Lake	River Raisin	Norvell, Mich.	58.5	25.3	-- --	--	717.6	.026	--	--	--	SCS
	do	do	do	--	--	May 1969	100±	502.3	.018	23.3	.085	43	
22-17	Sharon Hollow	do	Manchester, Mich.	34.7	25	-- 1927	--	258.1	.016	--	--	--	SCS
	do	do	do	--	--	May 1969	42	143.9	.009	30.1	.11	72	
22-18	Brooklyn Mill Pond	do	Brooklyn, Mich.	29.6	6.2	-- 1948	--	249.3	.016	--	--	--	SCS
	do	do	do	--	--	May 1969	21	186.3	.012	43.4	.484	457	
22-19	Manchester Power Dam	do	Manchester, Mich.	6.4	6.4	-- 194[illegible]	--	288.9	.09	--	--	--	SCS
	do	do	do	--	--	May 1969	23	259.5	.08	31.5	.20	137	
22-20	Iron Mill Pond	Iron Creek	do	14.4	5.2	-- --	--	1,551	.224	--	--	--	SCS
	do	do	do	--	--	Aug. 1969	100	1,159	.168	--	.75	--	
22-21	Phoenix Pond	Middle River Rouge	Plymouth, Mich.	56.85	56.85	-- --	--	225	.0074	--	--	--	SCS
	do	do	do	--	--	Sept. 1969	100	170	.0056	41.8	.0097	8.8	
22-22	Saline Mill Pond	Saline River	Saline, Mich.	73.6	63	-- 1937	--	240.1	.0061	--	--	--	SCS
	do	do	do	--	--	Mar. 1969	31	129.6	.0033	44	.057	54	
22-23	Manchester Mill Pond	Raisin River	Manchester, Mich.	17	17	-- 1906	--	21.33	.0026	--	--	--	SCS
	do	do	do	--	--	May 1969	63	10.9	.0013	38	.01	8	
22-24	Bridgeway Lake	Unnamed	Dexter, Mich.	7.5	7.5	-- 1927	--	76.7	.0250	--	--	--	SCS
	do	do	do	--	--	Mar. 1969	41	47.9	.0156	46	.093	93	
22-25	Franklin Mill Pond	Franklin Branch Rouge	Franklin, Mich.	13.8	7.8	-- 1833	--	97.8	.0133	--	--	--	SCS
	do	do	do	--	--	Apr. 1969	136	13.1	.0018	50	.079	86	
22-26	Waterford Pond	Middle River Rouge	Northville, Mich.	54	54	-- --	--	173	.0067	--	--	--	SCS
	do	do	do	--	--	Sept. 1969	100	101	.0039	39	.013	11	

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22-27	Tecumseh Mill Pond	Evans Creek	Tecumseh, Mich.	31.6	26.3	--	1827	--	227.8	.01501	--	--	--	SCS
	-----do	-----do	-----do	--	--	Apr.	1969	142	94.7	.0062	59	.0356	45	
22-28	Belleville Lake	Huron River	Belleville, Mich.	810	20.3	--	1929	--	19,945	.0513	--	--	--	SCS
	-----do	-----do	-----do	--	--	July	1969	40	17,980	.0462	69	2.42	3,637	
22-29	Ford Lake	-----do	Ypsilanti, Mich.	790	11.2	--	1933	--	17,926	.0472	--	--	--	SCS
	-----do	-----do	-----do	--	--	July	1969	36	16,085	.0424	81	4.56	8,045	
22-30	Barton Pond	-----do	Ann Arbor, Mich.	708	183	--	1915	--	3,150	.0083	--	--	--	SCS
	-----do	-----do	-----do	--	--	July	1969	54	2,601	.0068	39	.055	46	
22-31	Red Mill Pond	Upper Raisin	Tecumseh, Mich.	172.9	25.9	--	--	--	677	.0081	--	--	--	SCS
	-----do	-----do	-----do	--	--	Aug.	1969	100+	336	.0040	41.9	.13	118	
22-32	H. N. Fry Pond	Squaw Creek	Onstead, Mich.	12.45	12.45	Early	1962	--	121.3	.020	--	--	--	SCS
	-----do	-----do	-----do	--	--	Aug.	1969	7	116	.019	--	.06	--	
22-33	Newburgh Lake	Middle Rouge	Plymouth, Mich.	54.3	54.3	--	1933	--	667.8	.026	--	--	--	SCS
	-----do	-----do	-----do	--	--	Sept.	1969	36	562.9	.022	56.08	.054	65.96	
22-34	Lake Adrian	Wolf Creek	Adrian, Mich.	65	59	--	1942	--	1,000	.032	--	--	--	SCS
	-----do	-----do	-----do	--	--	Sept.	1969	28	851	.027	75.1	.09	147	

GREAT LAKES DRAINAGE (IN MICHIGAN AND WISCONSIN)

23-

MISSISSIPPI RIVER BASIN (LOUISIANA TO CHESTER) ILLINOIS, KASKASKIA, AND MERAMEC RIVER BASINS

24-1a	Lake Williamson (Artic Pond)	Trib. of Honey Creek	Carlinville, Ill.	.53	.51	--	1922	--	175.6	.614	--	--	--	IWS
	-----do	-----do	-----do	--	--	--	1949	27	159.5	.598	46.24	1.18	1,188	
	-----do	-----do	-----do	--	--	--	1954	5	152.2	.532	46.24	2.90	2,921	
	-----do	-----do	-----do	--	--	--	1961	7	147.6	.516	46.24	1.25	1,259	
24-2b	Lake Bloomington	Money Creek	Hudson, Ill.	61	60	Dec.	1929	--	6,654	1.980	--	--	--	IWS
	-----do	-----do	-----do	--	--	Aug.	1948	18.7	6,062	1.805	41.5	.528	477	
	-----do	-----do	-----do	--	--	Aug.	1952	4.0	5,905	1.756	41.5	.655	592	
	-----do	-----do	-----do	--	--	July	1955	2.9	5,863	1.746	46	.242	243	
24-3b	Lake Carlinville	Honey Creek	Carlinville, Ill.	26.06	25.79	June	1939	--	1,725	.118	--	--	--	IWS
	-----do	-----do	-----do	--	--	June	1949	10.4	1,475	.101	59.1	.934	1,200	
	-----do	-----do	-----do	--	--	July	1954	5.1	1,427	.098	65.7	.365	521	
	-----do	-----do	-----do	--	--	Sept.	1959	5.1	1,387	.095	62.4	.302	480	
24-4a	Lake Decatur	Sangamon River	Decatur, Ill.	906	902	Apr.	1922	--	19,738	--	--	--	--	SCS
	-----do	-----do	-----do	--	--	July	1936	14.2	16,930	--	--	.220	248	
	-----do	-----do	-----do	--	--	June	1946	10.0	14,567	--	51.7	.262	295	
24-5	Shaefer Pond	Trib. of Cahokia Creek	Edwardsville, Ill.	.087	.083	Nov.	1937	--	20.2	--	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1949	11.8	17.6	--	*50	2.65	2,890	
24-6	Lake Springfield	Sugar and Lick Creeks	Springfield, Ill.	265	258	Jan.	1934	--	61,039	--	--	--	--	IWS
	-----do	-----do	-----do	--	--	Aug.	1948	14.6	58,380	--	43	.705	660	
24-7	Spring Lake	Spring Creek	Macomb, Ill.	20.2	20.1	Apr.	1927	--	607	--	--	--	--	IWS
	-----do	-----do	-----do	--	--	Sept.	1947	20.4	320	--	59.7	.701	911	
24-8	Lake Bracken	Brush Creek	Galesburg, Ill.	9.14	8.85	Dec.	1923	--	2,881	--	--	--	--	IWS
	-----do	-----do	-----do	--	--	Aug.	1936	12.7	2,660	--	--	1.97	2,231	
	-----do	-----do	-----do	--	--	June	1949	12.9	2,452	--	52	1.82	2,061	
24-9	Pittsfield	Trib. of Panther Creek	Pittsfield, Ill.	1.84	1.77	June	1925	--	7/367	*.490	--	--	--	SCS
	-----do	-----do	-----do	--	--	Dec.	1946	21.5	232	*.310	*40	3.55	3,090	
24-10a	Lock and Dam 25 (Winfield)	Mississippi River	Winfield, Mo.	142,000	--	July	1939	--	180,000	--	--	--	--	CE
	-----do	-----do	-----do	--	--	May	1945	5.9	194,100	--	--	--	--	
	-----do	-----do	-----do	--	--	May	1946	1.0	181,400	--	--	--	--	
	-----do	-----do	-----do	--	--	Dec.	1947	1.6	184,000	--	--	--	--	
	-----do	-----do	-----do	--	--	May	1959	11.4	155,000	--	--	--	--	
24-11a	Mt. Sterling	Trib. of Shelby Creek	Mt. Sterling, Ill.	1.80	1.75	--	1935	--	306	.393	--	--	--	IWS
	-----do	-----do	-----do	--	--	--	1951	16	248	.319	60	2.05	2,679	
24-12	Lake Jacksonville	Sandy Creek	Jacksonville, Ill.	10.8	10.1	--	1939	--	7,058	1.167	--	--	--	IWS
	-----do	-----do	-----do	--	--	June	1952	12.0	6,874	1.137	32.5	1.51	1,069	
24-13	Mauvaisse Terre Lake	Mauvaissee Terre Creek	-----do	32.6	32.2	--	1921	--	1,820	.100	--	--	--	IWS
	-----do	-----do	-----do	--	--	June	1952	31	1,215	.067	48.2	.61	640	
24-14a	Morgan Lake	Unnamed	-----do	2.75	2.72	--	1900	--	126	.082	--	--	--	IWS
	-----do	-----do	-----do	--	--	June	1952	52	73	.047	41.2	.38	341	
24-15a	Langdon Pond	-----do	Franklin, Ill.	.358	.348	--	1907	--	56.8	.284	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	45	44.8	.224	31.8	.78	540	
24-16	Franklin Outing Club Lake	-----do	-----do	.450	.414	--	1905	--	328	1.302	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	47	301	1.194	52.4	1.43	1,632	
24-17	Anderson Lake	-----do	Concord, Ill.	.631	.600	--	1909	--	267	.756	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	43	234	.663	36.2	1.28	1,009	
24-18	Waverly City	-----do	Waverly, Ill.	9.24	9.16	Oct.	1938	--	308.3	.060	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	13.8	238.6	.046	42.4	.551	509	
24-19	Whitehall City	-----do	Whitehall, Ill.	.97	.92	--	1897	--	459	.846	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	55	408	.751	43.1	1.02	957	
24-20	Roodhouse Park District Lake	-----do	Roodhouse, Ill.	.451	.439	--	1917	--	61.6	.243	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	35	53.9	.213	42.4	.50	462	
24-21	Woodbine Country Club Lake	-----do	Greenfield, Ill.	.329	.320	--	1926	--	58.5	.318	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	26	43.6	.236	54.4	1.81	2,144	
24-22	Dale Cole Pond	-----do	-----do	.231	.221	--	1924	--	67.2	.521	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	28	56.7	.440	53.7	1.72	2,012	
24-23	Seely Pond	-----do	Hillview, Ill.	.093	.091	--	1902	--	3.7	.071	--	--	--	IWS
	-----do	-----do	-----do	--	--	July	1952	50	2.2	.042	35.6	.30	233	

1/ Sediment pool only.
2/ Also known as Lake St. Marys.
3/ At present spillway elevation (lowered in 1856). In 184- surface area was 17,603 acres and storage capacity was 220,400 ac.-ft.
4/ Capacity and sediment figures include that of several tributary arms including Beetree, Eagle and Sixmile Creeks.
5/ Tributary arm of Auglaize River Power Reservoir.
6/ All figures subject to readjustment because of minor dredging which occured in 1953.
7/ At present spillway elevation; spillway raised 1.24 ft. in 1944.
* Estimated or assumed.

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
MISSISSIPPI RIVER BASIN (LOUISIANA TO CHESTER) ILLINOIS, KASKASKIA, AND MERAMEC RIVER BASINS (Continued)													
24-24	Vinerard Pond	Unnamed	Whitehall, Ill.	0.054	0.052	Jan. 1937	—	1.58	.099	—	—	—	SCS
	do	do	do	—	—	July 1952	15.6	1.32	.066	90.3	0.33	260	
24-25	Kemp	do	Springfield, Ill.	3.49	3.43	— 1907	—	165.8	.093	—	—	—	SCS
	do	do	do	—	—	Aug. 1952	45	115.3	.059	38.7	.631	383	
24-26	Aschauer Pond	do	Riverton, Ill.	.526	.518	— 1939	—	10.3	.042	—	—	—	SCS
	do	do	do	—	—	Aug. 1952	13	9.6	.032	56.2	1.35	1,605	
24-27	Schmidt Pond	do	Chatham, Ill.	1.31	1.30	— 1943	—	6.8	.028	—	—	—	SCS
	do	do	do	—	—	Aug. 1952	9	3.6	.015	48.2	.32	197	
24-28	Ayers	Trib. of Shoal Creek	Ayers, Ill.	1.43	1.39	— 1906	—	205	.262	—	—	—	SCS
	do	do	do	—	—	Aug. 1958	52	190	.197	51.05	.69	766.07	
24-29a	Bodeman Reservoir	Trib. of West Creek	Brunswick, Ind.	2.73	2.39	Aug. 1947	—	52.1	*.036	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	13	46.8	*.031	56.7	.23	284	
24-30	C B & Q R. R. Lake	Trib. of Sangamon River	Tallula, Ill.	.85	.84	— 1922	—	31.7	.067	—	—	—	SCS
	do	do	do	—	—	July 1952	30	15.6	.033	69.9	.39	659	
24-31	Edwards Lake	Trib. of Cahokia Creek	Gillespie, Ill.	.62	.60	— 1949	—	76.2	.391	—	—	—	SCS
	do	do	do	—	—	Aug. 1958	9	60.5	.322	46.06	1.72	1,795.67	
24-32	Blohmann's Lake	Trib. of Kaskaskia River	Vandalia, Ill.	.27	.26	— 1943	—	30.7	.177	—	—	—	SCS
	do	do	do	—	—	Aug. 1958	15	16.0	.111	55.66	.93	1,127.33	
24-33	Glasier No. 1	Lost Creek	Elsberry, Mo.	1.05	1.04	Apr. 1960	—	1/72.5	—	—	—	—	SCS
	do	do	do	—	—	July 1966	6.3	70.3	—	—	.48	—	
24-34	I. C. at Kinmundy	Trib. of East Fork of Kaskaskia River	Kinmundy, Ill.	.618	.585	— 1852	—	376.34	.449	—	—	—	SCS
	do	do	do	—	—	July 1949	97	149.10	.323	35.5	.716	984.5	
24-35	King's Lake	Trib. of Cahokia Creek	Eagarville, Ill.	.46	.44	— 1921	—	158.6	.466	—	—	—	SCS
	do	do	do	—	—	June 1958	37	139.5	.398	56.62	1.17	1,386.73	
24-36	Lake Coulterville	South Fork Mud Creek	Coulterville, Ill.	1.22	1.18	— 1920	—	205	.276	—	—	—	SCS
	do	do	do	—	—	Aug. 1954	34	188	.260	56	.73	943	
24-37	Lake Bunker Hill	Wood River	Bunker Hill, Ill.	7.19	7.15	— 1937	—	133	.033	—	—	—	SCS
	do	do	do	—	—	June 1954	17	36	.009	79.2	.80	1,380	
24-38	Lake Gillespie	Dry Fork	Gillespie, Ill.	5.73	5.62	— 1923	—	799	.272	—	—	—	SCS
	do	do	do	—	—	July 1955	32	696	.237	77.0	.97	670	
24-39	Lake Nashville	Nashville Creek	Nashville, Ill.	1.39	1.33	— 1936	—	320	.376	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	19	289	.339	35.3	1.10	913	
24-40	Lake Staunton	East Creek	Staunton, Ill.	3.68	3.56	— 1926	—	1,260	.630	—	—	—	SCS
	do	do	do	—	—	July 1954	28	1,140	.575	30.1	1.00	667	
24-41	Macoupin County Lake Club	Trib. of Hurricane Creek	Carlinville, Ill.	.28	.26	— 1902	—	160.5	1.135	—	—	—	SCS
	do	do	do	—	—	June 1958	56	135.8	.976	77.13	1.96	1,423.32	
24-42a	Mine Pond No. 4	Trib. of Cahokia Creek	Wilsonville, Ill.	5.29	5.23	— 1916	—	296.1	.180	—	—	—	SCS
	do	do	do	—	—	July 1958	42	142.6	.093	65.36	.70	996	
24-43	New Mt. Olive	do	White City, Ill.	5.21	5.12	— 1938	—	632.6	.166	—	—	—	SCS
	do	do	do	—	—	June 1958	20	335.1	.137	52.35	.96	1,075.79	
24-44a	Panama Lake	Trib. of Indian Creek	Panama, Ill.	.85	.84	— 1928	—	177.8	.596	—	—	—	SCS
	do	do	do	—	—	Aug. 1958	30	151.9	.458	68.2	1.03	1,230	
24-45	Power Farms Ponds	Trib. of Sangamon River	Cantrall, Ill.	.668	.666	— 1940	—	6.2	.081	—	—	—	SCS
	do	do	do	—	—	July 1952	12	1.3	.007	56.9	.36	438	
24-46	Raccoon Lake	Raccoon Creek	Centralia, Ill.	48.4	47.3	— 1943	—	6,496.3	.152	—	—	—	SCS
	do	do	do	—	—	Sept. 1959	16	6,343.6	.148	39.7	.67	486	
24-47	Robinson Pond	Terre Creek	Jacksonville, Ill.	.316	.306	— 1930	—	67.1	.277	—	—	—	SCS
	do	do	do	—	—	July 1952	22	39.6	.209	66.8	.70	713.51	
24-48	Salem City	Trib. of Crooked Creek	Salem, Ill.	4.02	3.90	— 1912	—	997.86	.371	—	—	—	SCS
	do	do	do	—	—	Aug. 1960	48	930.88	.307	60.6	.36	530	
24-49a	Virginia	Job's Creek	Virginia, Ill.	.828	.799	— 1933	—	156	.365	—	—	—	SCS
	do	do	do	—	—	— 1950	17	116	.260	*40	2.70	2,352	
24-50	Walton Club Lake	Long Branch	Litchfield, Ill.	2.72	2.67	— 1852	—	376.3	.272	—	—	—	SCS
	do	do	do	—	—	July 1949	97	197.2	.136	48.6	.73	789.5	
24-51	Lock and Dam 26	Mississippi River	Alton, Ill.	171,470	—	May 1938	—	395,000	—	—	—	—	CE
	do	do	do	—	—	May 1945	7.1	390,200	—	—	—	—	
	do	do	do	—	—	Dec. 1945	.6	—	—	—	—	—	
	do	do	do	—	—	May 1946	.4	385,200	—	—	—	—	
	do	do	do	—	—	Oct. 1947	1.4	400,200	—	—	—	—	
	do	do	do	—	—	Apr. 1959	11.5	363,900	—	—	—	—	
24-52a	Pool No. 22	do	Saverton, Mo.	137,500	—	July 1938	—	93,838	—	—	—	—	CE
	do	do	do	—	—	Dec. 1954	16.33	85,271	.0017	—	.006	—	
	do	do	do	—	—	Dec. 1969	15	2/102,362	.0018	—	—	—	

UPPER MISSISSIPPI RIVER BASIN (FAIRMONT TO LOUISIANA)
Iowa, Skunk, and Des Moines River Basins

25-1	Pool No. 19 (Lake Cooper, Keokuk Dam)	Mississippi River	Keokuk, Iowa	119,000	—	—	1913	—	479,590	—	—	—	—	CE
	do	do	do	—	—	June	1928	15	370,300	—	—	—	—	
	do	do	do	—	—	June	1938	10	337,000	—	—	—	—	
	do	do	do	—	—	June	1946	8	313,316	—	—	—	—	
25-2	Upper Pine	Pine Creek	Eldora, Iowa	13.9	13.8	May	1934	—	660	.165	—	—	—	SCS
	do	do	do	—	—	Sept.	1947	13.3	452	.099	*60	1.16	*1,490	
25-3	Lake Calhoun	Fitch Creek	Galva, Ill.	13.1	13.0	Sept.	1924	—	2/435	—	—	—	—	IWS
	do	do	do	—	—	Aug.	1936	11.9	373	—	—	.977	1,390	
	do	do	do	—	—	July	1947	11.0	312	—	56	1.12	1,370	
25-4	Carthage	Long Creek	Carthage, Ill.	2.96	2.88	Mar.	1926	—	466.3	—	—	—	—	IWS
	do	do	do	—	—	Aug.	1949	23.4	308.2	—	*50	1.45	1,980	
25-5	McCraney Creek New Desilting Basin	McCraney Creek	Kinderhook, Ill.	52.0	50.2	Dec.	1936	—	*2,400	—	—	—	—	SCS
	do	do	do	—	—	Dec.	1939	3	*1,770	—	*85	6.18	7,760	
	do	do	do	—	—	—	1941	2	*1,464	—	*85	1.08	1,960	
25-6	Pine Lake	Pine Creek	Eldora, Iowa	15.36	15.26	—	1924	—	738	*.168	—	—	—	SCS
	do	do	do	—	—	Winter	1932	8	552	*.111	*60	1.52	*1,990	
25-7	Hadley Creek Old Desilting Basin	Hadley Creek	New Canton, Ill.	77.0	4/72.7	—	1921	—	3,000	*.067	—	—	—	SCS
	do	do	do	—	—	—	1936	15	1,845	*.061	*85	1.06	1,960	
25-8	Hadley Creek New Desilting Basin	do	do	77.0	4/72.7	Dec.	1936	—	3,080	*.068	—	—	—	SCS
	do	do	do	—	—	Dec.	1939	3	2,556	*.097	*85	2.44	4,460	
25-9	Kiser Creek Desilting Basin	Kiser Creek	do	66.0	5/59.6	Dec.	1936	—	*2,800	*.073	—	—	—	SCS
	do	do	do	—	—	Dec.	1939	3	*2,290	*.059	*85	2.85	5,280	
25-10	Beeds Lake	Unnamed	Hampton, Iowa	31.8	31.6	—	1935	—	1,156	*.089	—	—	—	SCS
	do	do	do	—	—	—	1946	11	1,079	*.066	*65	.24	360	
25-11	C M St. P & P RR Res.	Trib. of Big Creek	Madrid, Iowa	2.56	2.52	—	1903	—	43	*.069	—	—	—	SCS
	do	do	do	—	—	—	1918	15	25	*.060	*70	.476	726	
25-12a	Fairfield No. 3	Crow Creek	Fairfield, Iowa	2.05	2.00	—	1927	—	207	*.303	—	—	—	SCS
	do	do	do	—	—	—	1934	7	166	*.262	*51.6	2.96	3,327	
	do	do	do	—	—	July	1953	19	135	*.198	51.6	.795	893	
25-13	Springbrook	Spring Brook	Guthrie Center, Iowa	2.1	2.1	—	1936	—	185	*.386	—	—	—	SCS
	do	do	do	—	—	—	1946	10	172	*.359	*50	.638	605	
25-14	Pool No. 16	Mississippi River	Muscatine, Iowa	99,400	—	Mar.	1938	—	113,370	—	—	—	—	CE
	do	do	do	—	—	Nov.	1949	11.7	106,367	—	—	—	—	
25-15	Pool No. 20	do	Canton, Mo.	134,300	—	Oct.	1937	—	69,830	—	—	—	—	CE
	do	do	do	—	—	Nov.	1950	13.1	67,760	—	—	—	—	
25-16	Bloomfield	Unnamed	Bloomfield, Iowa	2.25	2.13	Sept.	1937	—	898	*.464	—	—	—	SCS
	do	do	do	—	—	Sept.	1951	14.0	831	*.424	*60	2.16	2,833	
25-17	Pool No. 17	Mississippi River	New Boston, Ill.	99,600	—	Aug.	1938	—	70,800	—	—	—	—	CE
	do	do	do	—	—	Mar.	1954	15.6	69,350	—	—	.008	—	
25-18	Pool No. 21	do	Quincy, Ill.	135,000	—	July	1938	—	78,040	—	—	—	—	CE
	do	do	do	—	—	Mar.	1954	15.7	69,970	—	—	.006	—	
25-19a	Coralville	Iowa River	Iowa City, Iowa	3,115	3,076	Sept.	1958	—	492,000	.67	—	—	—	CE
	do	do	do	—	—	Jan.	1964	5.33	485,400	.66	60	.402	390.2	
	do	do	do	—	—	Apr.	1968	6.33	490,110	.66	65	.397	443.2	

UPPER MISSISSIPPI RIVER BASIN (PRAIRIE DU CHIEN TO ROCK ISLAND) AND LAKE MICHIGAN DRAINAGE
Rock and Wapsipinicon River Basins

26-1a	Pool No. 15	Mississippi River	Rock Island, Ill.	88,900	—	Mar.	1934	—	39,437	—	—	—	—	CE
	do	do	do	—	—	Aug.	1938	6.5	38,566	—	—	.003	—	
	do	do	do	—	—	Nov.	1944	6.2	38,229	—	—	.003	—	
	do	do	do	—	—	Dec.	1946	2.1	39,236	—	—	-.005	—	
	do	do	do	—	—	Nov.	1948	1.9	37,463	—	—	.009	—	
	do	do	do	—	—	Nov.	1950	2.0	37,883	—	—	-.008	—	
	do	do	do	—	—	Nov.	1952	2.0	37,886	—	—	.006	—	
26-2	Backbone Lake (Forestville Lake)	Maquoketa River	Strawberry Pt., Iowa	116	116	July	1934	—	608	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1942	7.6	590	—	—	.078	137	
	do	do	do	—	—	Feb.	1949	7.0	473	—	75.3	.082	136	
26-3	Pool No. 11	Mississippi River	Dubuque, Iowa	81,600	—	Apr.	1938	—	171,486	—	—	—	—	CE
	do	do	do	—	—	Feb.	1953	14.8	156,530	—	—	.016	—	

UPPER MISSISSIPPI RIVER BASIN (ST. PAUL TO PRAIRIE DU CHIEN)
Wisconsin, Root, Chippewa, and St. Croix River Basins

27-1	Elk Creek Lake	Elk Creek	Eau Claire, Wisc.	60	60	—	1936	—	683	*.018	—	—	—	SCS
	do	do	do	—	—	Oct.	1951	15	677	*.013	*70	.252	384	
27-2	Ettrick Mill Pond	N. Br. Beaver Creek	Ettrick, Wisc.	50.75	50.75	—	1875	—	127	—	—	—	—	SCS
	do	do	do	—	—	June	1939	64	46	—	*80	.083	60	
27-3	Marinuka (Davis Lake)	Beaver Creek	Galesville, Wisc.	138.6	138.2	—	1867	—	1,677	*.082	—	—	—	SCS
	do	do	do	—	—	June	1939	72	683	*.089	72.5	.100	158	
27-4	Prairie du Sac	Wisconsin River	Prairie du Sac, Wisc.	8,900	6/600	—	1914	—	100,000	—	—	—	—	CE
	do	do	do	—	—	—	1933	19	91,451	—	*90	.737	1,400	

1/ Conservation Pool.
2/ All 31 ranges show scour, partially due to removal of borrow material.
3/ Spillway raised 2.89 ft. in 1946. Original capacity was 285.6 ac.-ft. All sedimentation and storage loss data based on higher spillway elevation.

4/ Excludes 3.8 sq. mi. Mississippi River bottom land.
5/ Excludes 5.8 sq. mi. Mississippi River bottom land.
6/ Flow from 8,300 sq. mi. of drainage area passes through power dams, which act as silt traps.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG ANN INFLOW RATIO (ACRE-FT PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	UPPER MISSISSIPPI RIVER BASIN (ST. PAUL TO PRAIRIE DU CHIEN) WISCONSIN, ROOT, CHIPPEWA, AND ST. CROIX RIVER BASIN (Continued)												
27-5	Pool No. 5A	Mississippi River	Winona, Minn. - Wisc.	59,100	--	July 1936	--	30,000	--	--	--	--	CE
	do	do	do	--	--	Feb. 1945	8.6	29,900	--	*90	--	--	
27-6a	DA-1 - Fishbaugher	Trib. D. E. Willow Creek	Preston, Minn.	1.31	1.29	Nov. 1956	--	168.7	.676	--	--	--	SCS
	do	do	do	--	--	Mar. 1960	3.6	166.5	.668	*90	0.51	778	
	do	do	do	--	--	Apr. 1966	6.1	164.3	.661	*90	.63	696	
27-7	Franklin Farm Pond	Trib. of Spring Creek	Red Wing, Minn.	1.188	1.181	May 1958	--	110.5	*.341	--	--	--	SCS
	do	do	do	--	--	June 1962	6.1	104.56	*.327	*65	1.23	1,763	
27-8	Frieheit Farm Pond	Trib. of Zumbro River	Zumbro Falls, Minn.	.269	.268	Aug. 1955	--	14.27	*.166	--	--	--	SCS
	do	do	do	--	--	May 1962	6.8	13.29	*.155	69.5	.52	560	
27-9	Stelplaugh Farm Pond	Trib. of Corey Creek	Money Creek, Minn.	.231	.230	Sept. 1955	--	19.09	*.313	--	--	--	SCS
	do	do	do	--	--	May 1962	6.7	18.04	*.296	*65	.86	1,359	
27-10	Wahl'fiel Farm Pond	Trib. of Zumbro River	Millville, Minn.	.386	.384	July 1955	--	27.40	*.227	--	--	--	SCS
	do	do	do	--	--	May 1962	6.8	26.75	*.219	*55	.69	587	
27-11	Wold Farm Pond	Trib. of Crooked Creek	Spring Grove, Minn.	.194	.193	Aug. 1954	--	10.40	*.157	--	--	--	SCS
	do	do	do	--	--	Jan. 1962	7.3	10.03	*.150	51.06	.331	376	
27-12	PB-28 Structure East Willow Creek Watershed	Trib. of Root River	Preston, Minn.	.636	.633	Oct. 1954	--	56.79	*.666	--	--	--	SCS
	do	do	do	--	--	June 1962	7.7	55.18	*.631	*65	.60	640	
27-13	E-3 Mensink	Trib. of E.E. Willow Creek	do	3.16	3.10	May 1956	--	292.2	.360	--	--	--	SCS
	do	do	do	--	--	Mar. 1960	3.83	291.0	.338	*90	.11	120	
	do	do	do	--	--	Apr. 1966	6.08	287.2	.334	*90	.30	130	
	UPPER MISSISSIPPI RIVER BASIN (ABOVE ST. PAUL)												
28-	LAKE SUPERIOR AND LAKE OF THE WOODS AREA (IN MINNESOTA)												
29-	RED RIVER OF THE NORTH BASIN												
30-1	Lake Bronson	Two Rivers	Bronson, Minn.	439	438.5	Summer 1940	--	3,792	--	--	--	--	SCS
	do	do	do	--	--	Oct. 1950	10	3,646	--	30.96	.038	25.6	
30-2	Frazee	Otter Tail River	Frazee, Minn.	210	34	-- 1926	--	155	--	--	--	--	SCS
	do	do	do	--	--	May 1952	26	157.1	--	30	.089	12.6	
30-3	Blabon Dam	Trib. of Goose River	Blabon, N. Dak.	1.219	1.188	-- 1935	--	110.49	*3.356	--	--	--	SCS
	do	do	do	--	--	Oct. 1955	20	107.29	*2.753	65	.98	875	
30-4	Dougherty Dam	N. Br. Forest River	Adams, N. Dak.	20.2	16.6	-- 1935	--	150.7	*.209	--	--	--	SCS
	do	do	do	--	--	Aug. 1957	22	139.6	*.196	25	.036	18.85	
30-5	Gustafson Farm Pond	Park River	do	3.755	3.670	-- 1941	--	38.70	*.286	--	--	--	SCS
	do	do	do	--	--	May 1955	14	33.36	*.245	*55	.105	76.99	
30-6	Geismer Dam	Trib. of Wild Rice River	Geismer, N. Dak.	.226	.222	-- 1936	--	12.97	*2.696	--	--	--	SCS
	do	do	do	--	--	Aug. 1956	20	10.29	*1.986	39	.59	972.6	
30-7	Madsen Farm Pond	Swan Creek	Wheatland, N. Dak.	27.76	27.76	-- 1939	--	22.82	*.026	--	--	--	SCS
	do	do	do	--	--	June 1956	17	19.10	*.022	*55	.0078	5.95	
30-8	Magnolia Dam	Buffalo Creek	do	12.16	11.72	-- 1908	--	197.92	*.606	--	--	--	SCS
	do	do	do	--	--	June 1956	48	177.65	*.528	*55	.052	39.64	
30-9	Mason Siding Dam	Rush River	Erie, N. Dak.	90.2	90.2	-- 1912	--	63.14	*.065	--	--	--	SCS
	do	do	do	--	--	June 1956	44	35.61	*.037	*55	.0058	6.66	
30-10	Malvin Bellerud Farm Pond	Park River	Adams, N. Dak.	1.125	1.121	-- 1942	--	16.78	*.452	--	--	--	SCS
	do	do	do	--	--	May 1955	13	14.67	*.355	*55	.1379	116.60	
30-11	Milton WPA Dam	do	Milton, N. Dak.	14.375	14.356	-- 1934	--	66.99	*.128	--	--	--	SCS
	do	do	do	--	--	May 1955	21	60.19	*.089	*55	.0076	51.93	
30-12	Morby Dam	Trib. of Wild Rice River	Havana, N. Dak.	.187	.185	-- 1934	--	5.227	*1.191	--	--	--	SCS
	do	do	do	--	--	Aug. 1956	22	4.667	*1.018	*65	.188	184.3	
30-13	Raleigh Dam	Dog Tooth Creek	Raleigh, N. Dak.	4.65	4.65	-- 1939	--	175.67	*.925	--	--	--	SCS
	do	do	do	--	--	July 1956	17	165.21	*.786	*55	.166	109.8	
30-14	Sioux Railroad Reservoir	Park River	Adams, N. Dak.	16.855	16.66	-- 1911	--	88.37	*.165	--	--	--	SCS
	do	do	do	--	--	May 1955	44	64.16	*.113	*55	.036	18.88	
30-15	White Lake	Trib. of Wild Rice River	Havana, N. Dak.	37.0	21.08	-- 1938	--	1,095.6	--	--	--	--	SCS
	do	do	do	--	--	-- 1957	19	1,088.0	--	32	.2167	151	
30-16	Baldhill Dam (Lake Ashtabula)	Sheyenne River	Valley City, N. Dak.	1/6,138	2/1,970	Dec. 1952	--	76,600	--	--	--	--	CE
	do	do	do	--	--	Jan. 1958	5.1	75,650	--	*90	.0985	192	
30-17	Homme Dam (Park River)	S. Br. Park River	Park River, N. Dak.	229	229	Jan. 1953	--	3,690	.206	--	--	--	CE
	do	do	do	--	--	Mar. 1958	5.2	3,582	.189	*90	.225	441	
	MISSOURI RIVER BASIN (NEBRASKA CITY TO HERMANN)												
31-1	Lake of the Ozarks (Bagnell Dam)	Osage River	Eldon, Mo.	14,000	13,900	Feb. 1931	--	2,087,223	.299	--	--	--	CE
	do	do	do	--	--	Oct. 1948	17.6	1,972,551	.283	90.2	.466	918	
31-2	Carl Chinquist	Trib. of West Nodaway River	Stanton, Iowa	.166	.163	June 1938	--	3/9.46	*.231	--	--	--	SCS
	do	do	do	--	--	May 1949	10.9	2.59	*.069	49.9	3.07	6,200	

11-3	L. R. Poulding	Trib. of Tarkio Creek	Westboro, Mo.	1.05	1.06	July	1939	--	3/31.80	*.132	--	--	--	SCS
	do	do	do	--	--	May	1949	9.8	1.99	*.088	68.5	7.93	3,900	
11-4	McDaniel Lake	Little Sac River	Springfield, Mo.	41.9	41.5	--	1939	--	3,650	--	--	--	--	SCS
	do	do	do	--	--	June	1950	11	3,397	--	460	.138	793	
11-5	Doniphan Co. Old Desilting Basin	Chase Creek	Blair, Kans.	1.62	1.58	--	1930	--	159.2	*.316	--	--	--	SCS
	do	do	do	--	--	June	1937	4/10.0	23.6	*.046	86.6	8.58	15,770	
11-6	Leavenworth Co. State Lake	Unnamed Trib.	Tonganoxie, Kans.	3.83	3.56	Sept.	1951	--	3,816	3.705	--	--	--	SCS
	do	do	do	--	--	Nov.	1967	16.1	3,771	3.964	64.45	2.53	3,386	
11-7	Lyon Co. State (Reading Lake)	do	Reading, Kans.	2.19	5/1.79	--	1935	--	1,897	*3.428	--	--	--	SCS
	do	do	do	--	--	Aug.	1939	4.0	1,870	*3.396	460	7.73	3,560	
11-8	Martin Farm Lake	Osage River	Ottawa, Kans.	.18	.17	Nov.	1930	--	33	*.593	--	--	--	SCS
	do	do	do	--	--	Oct.	1937	6.9	30	*.908	460	2.83	3,465	
11-9b	Mission Lake	Mission Creek	Horton, Kans.	8.15	7.76	May	1926	--	1,866	*1.035	--	--	--	ARS
	do	do	do	--	--	Apr.	1937	11	1,563	*.838	62.8	3.03	4,064	
	do	do	do	--	--	July	1954	17.2	1,185	*.669	53.3	2.68	3,336	
	do	do	do	--	--	Aug.	1967	13.1	1,093.5	*.599	58.5	.88	12.65	
11-10	Moran	S. Fk. Osage River	Moran, Kans.	5.95	5.28	Apr.	1933	--	365	*.130	--	--	--	SCS
	do	do	do	--	--	Sept.	1959	26.4	298	*.106	69.15	.677	511	
11-11	Lake Olathe	Cedar Creek	Olathe, Kans.	6.20	6.11	July	1932	--	731	--	--	--	--	SCS
	do	do	do	--	--	June	1937	4.9	666	--	60.4	1.84	2,431	
	do	do	do	--	--	July	1949	12.1	608	--	97.6	2.61	3,083	
11-12	Richmond	Unnamed Trib.	Richmond, Kans.	2.17	2.07	--	1939	--	405	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1977	38	289	--	460	2.00	2,444	
11-13	Lampe Farm Pond	Trib. of Muddy Creek	Howe, Nebr.	.065	.064	Aug.	1962	--	3.00	*.231	--	--	--	SCS
	do	do	do	--	--	Dec.	1968	6.3	2.06	*.157	97.6	2.61	3,080	
11-14	E. W. Howell	Trib. of Tarkio Creek	Tarkio, Mo.	.509	.505	July	1936	--	3/33.7	*.303	--	--	--	SCS
	do	do	do	--	--	May	1949	6/6.9	.03	*.0003	72.5	9.66	15,250	
11-15	Allerton	South Chariton River	Allerton, Iowa	6.98	6.82	--	1913	--	511	--	--	--	--	SCS
	do	do	do	--	--	Nov.	1939	25.5	405	--	460	.096	1,170	
11-16	Centerville No. 2	Manson's Branch	Centerville, Iowa	2.70	2.68	--	1926	--	1,111	--	--	--	--	SCS
	do	do	do	--	--	--	1937	11	1,090	--	460	2.15	2,760	
11-17	Lake of Three Fires	E. Fk. 102 River	Bedford, Iowa	6.15	5.97	July	1936	--	1,231	--	--	--	--	SCS
	do	do	do	--	--	Feb.	1950	13.6	860	--	--	6.58	--	
11-18	Dominey Reservoir	Longs Creek	Johnson, Nebr.	.703	.699	--	1952	--	13.6	--	--	--	--	SCS
	do	do	do	--	--	--	1958	6	10.7	--	465	.964	1,365	
11-19	Hadley Reservoir	Trib. of Nemaha River	Brock, Nebr.	.12	.115	--	1947	--	11.37	--	--	--	--	SCS
	do	do	do	--	--	--	1956	9	10.35	--	465	.963	1,334	
11-20a	Schneider Reservoir	Long Branch	Johnson, Nebr.	.188	.186	--	1952	--	10.6	--	--	--	--	SCS
	do	do	do	--	--	--	1958	6	6.23	--	465	5.65	8,030	
11-21	Cox	Unnamed Trib.	Blue Rapids, Kans.	.31	.30	June	1946	--	6.98	--	--	--	--	SCS
	do	do	do	--	--	Mar.	1955	8.8	4.05	--	67.22	1.10	1,410	
11-22	Droege	do	Osage City, Kans.	.4	.4	Mar.	1944	--	3/12.89	--	--	--	--	SCS
	do	do	do	--	--	Sept.	1955	11.5	8.4	--	60	.97	1,267	
11-23	Flinner	do	Leavenworth, Kans.	.66	.63	Nov.	1936	--	81.6	--	--	--	--	SCS
	do	do	do	--	--	Aug.	1957	20.7	26.1	--	460	6.22	5,515	
11-24	Honey Creek No. A-2	Trib. of Honey Creek	Russell, Iowa	.278	.276	Oct.	1956	--	52.7	*.750	--	--	--	SCS
	do	do	do	--	--	Oct.	1958	2.00	52.3	*.744	66	.75	1,000	
	do	do	do	--	--	Sept.	1959	.92	52.2	*.743	66	.76	1,100	
	do	do	do	--	--	Jan.	1961	1.33	52.2	*.743	66	0	0	
11-25	Honey Creek No. A-4	do	do	.355	.346	Aug.	1957	--	64.9	*.734	--	--	--	SCS
	do	do	do	--	--	Oct.	1958	1.17	63.5	*.708	66	3.12	3,100	
	do	do	do	--	--	Aug.	1959	.83	63.3	*.708	66	.75	1,000	
	do	do	do	--	--	Jan.	1961	1.42	63.3	*.708	66	0	0	
11-26	Honey Creek No. F-1	do	do	1.213	1.200	Nov.	1955	--	186	*.600	--	--	--	SCS
	do	do	do	--	--	Oct.	1958	2.92	181	*.590	66	.77	1,100	
	do	do	do	--	--	Oct.	1959	1.00	179	*.586	66	2.02	2,900	
	do	do	do	--	--	Jan.	1961	1.25	179	*.586	66	0	0	
11-27	Honey Creek No. E-1	Trib. of Honey Creek	Russell, Iowa	.478	.470	July	1955	--	142	*1.175	--	--	--	SCS
	do	do	do	--	--	June	1958	2.92	140	*1.158	66	1.35	1,930	
	do	do	do	--	--	Sept.	1959	1.25	138	*1.142	66	2.61	3,000	
	do	do	do	--	--	Jan.	1961	1.33	138	*1.142	66	0	0	
11-28	Honey Creek No. I-1	do	do	.503	.495	Nov.	1955	--	106	*.833	--	--	--	SCS
	do	do	do	--	--	Oct.	1958	2.92	105	*.826	66	.85	1,222	
	do	do	do	--	--	Sept.	1959	.92	104	*.818	66	2.23	3,300	
	do	do	do	--	--	Jan.	1961	1.33	104	*.818	66	0	0	
11-29	Miller Ranch	Unnamed Trib.	Miller, Kans.	.71	.70	Nov.	1936	--	52.72	--	--	--	--	SCS
	do	do	do	--	--	Sept.	1955	18.8	37.83	--	52.9	1.13	1,977	
11-30	Halte	Trib. of Wolf River	Hiawatha, Kans.	.62	.62	May	1949	--	3/7.55	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1955	6.0	5.49	--	68.43	1.18	1,649	
11-31	Prairie Lake	Unnamed Trib.	Holton, Kans.	1.69	1.60	Oct.	1947	--	721.7	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1955	8.0	693.1	--	56.3	6.12	7,297	
11-32	Wyhart	do	Effingham, Kans.	.16	.15	Oct.	1949	--	3/69.4	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1957	7.9	46.3	--	460	2.6	3,136	
11-33	Sabetha Lake	Deer Creek Trib. of Nemaha	Sabetha, Kans.	9.17	8.99	Jan.	1936	--	1,936	.486	--	--	--	ARS
	do	do	do	--	--	June	1951	15.5	1,310	.366	56.7	6.46	1,977	
	do	do	do	--	--	Aug.	1952	1.2	1,276	.353	55.7	7.06	6,900	
	do	do	do	--	--	Oct.	1953	1.1	1,299	.353	58.0	7/-2.52	--	
	do	do	do	--	--	Apr.	1955	1.5	1,306	.358	56.1	3.93	379	
	do	do	do	--	--	Apr.	1956	1.0	1,205	.355	55.0	.11	1,720	
	do	do	do	--	--	Apr.	1958	2.0	1,200	.477	56.2	.28	1,460	
	do	do	do	--	--	July	1960	2.3	1,137	.466	56.6	6.00	3,577	

1/ Total drainage area (exclusive of closed Devils Lake Basin with drainage area of 3,960 sq. mi.).
2/ About 2,150 sq. mi. of the total drainage area shown is also noncontributing.
3/ Water supply pool capacity. Reservoir has greater capacity at spillway crest elevation.
4/ Water diverted from basin after June, 1930.
5/ Excluding area of lake and 0.31 sq. mi. above stock pond.
6/ Reservoir silted full Dec. 1936; Crest raised June 1937; silted full again Dec. 1940; crest raised again May 1945; silted full again May 1949. Age computed as 6.9 yr.
7/ Minus (-) indicates scour or compaction (treated as negative sediment).
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
MISSOURI RIVER BASIN (NEBRASKA CITY TO HERMAN) (Continued)													
31-34	Sutter	Unnamed Trib.	Effingham, Kans.	.17	.16	Jan. 1950	--	1/53.2	--	--	--	--	SCS
	do	do	do	--	--	Oct. 1957	7.7	50.86	--	*60	1.88	2,457	
31-35	Shirley Pond	do	Lawrence, Kans.	.18	.18	Mar. 1939	--	20.86	--	--	--	--	SCS
	do	do	do	--	--	Nov. 1956	17.7	19.05	--	86.7	.56	1,057.5	
31-36	Trueman	do	Fairview, Kans.	.18	.18	May 1947	--	1/3.78	--	--	--	--	SCS
	do	do	do	--	--	Oct. 1955	8.4	2.42	--	62.01	.90	1,201	
31-37	Thorne	Unnamed	Effingham, Kans.	1.17	1.16	Sept. 1946	--	1/29.13	--	--	--	--	SCS
	do	do	do	--	--	Aug. 1957	11	17.7	--	*60	.90	1,176	
31-38b	Ashland Reservoir	Brushy Creek	Ashland, Mo.	3.78	3.75	Apr. 1937	--	280.48	--	--	--	--	ARS
	do	do	do	--	--	Nov. 1949	12.6	212.01	--	69	1.44	2,178	
	do	do	do	--	--	Apr. 1951	1.4	208.14	--	68	.73	807	
	do	do	do	--	--	July 1955	4.3	202.23	--	*68	.36	543	
	do	do	do	--	--	June 1962	6.9	186.07	--	69.4	.62	1,038	
	do	do	do	--	--	July 1968	6.1	171.52	--	64.7	.62	624	
31-39	Higginsville Old City Lake	Trib. of Davis Creek	Higginsville, Mo.	2,728	2,633	Sept. 1924	--	520.0	--	--	--	--	ARS
	do	do	do	--	--	July 1964	39.8	304.0	--	55.94	2.061	2,511	
31-40	Beecher	Trib. of Brush Creek	do	.334	2/.181	Oct. 1950	--	32.26	--	--	--	--	ARS
	do	do	do	--	--	Aug. 1964	13.8	25.55	--	58.74	2.686	3,436	
31-41	Mitchell	Trib. of Washington Creek	Lawrence, Kans.	.119	.117	Oct. 1949	--	7.94	--	--	--	--	SCS
	do	do	do	--	--	June 1962	12.67	6.73	--	56.8	.85	1,051	
31-42	McKee	do	Clinton, Kans.	.61	.58	Jan. 1950	--	6.77	--	--	--	--	SCS
	do	do	do	--	--	May 1962	12.4	6.26	--	47.9	.07	73	
31-43	Kennedy	Trib. of Wakarusa River	Richland, Kans.	.23	.22	Apr. 1937	--	61.19	--	--	--	--	SCS
	do	do	do	--	--	May 1962	25.1	56.27	--	46.7	1.27	1,294	
31-44	Jertsemberger	do	Eudora, Kans.	.135	.122	May 1955	--	1/7.52	--	--	--	--	SCS
	do	do	do	--	--	June 1962	7.1	5.68	--	56.2	2.15	2,609	
31-45	Lake Elbow	Trib. of Kansas River	Manhattan, Kans.	3.20	3.14	Spr. 1949	--	206	.303	--	--	--	SCS
	do	do	do	--	--	Sept. 1965	16.33	176	.259	75	.58	947	
31-46	Bokey	Trib. of Nemaha River	Sabetha, Kansas	.284	.280	May 1956	--	1/13.97	--	--	--	--	SCS
	do	do	do	--	--	Apr. 1962	5.9	11.32	--	50.7	1.61	1,777	
31-47	Callahan Cr. Watershed (C-1)	Barclay Branch	Columbia, Mo.	5.625	5.515	Apr. 1967	--	1,017.07	--	--	--	--	ARS
	do	do	do	--	--	Aug. 1967	.25	1,010.8	--	41.6	4.57	4,144	
	do	do	do	--	--	Aug. 1969	2	989.3	--	53	1.94	2,379	
	do	do	do	--	--	July 1971	1.9	974.9	--	58.2	1.38	2,059	
31-48	Wakefield	Trib. Marias Des Cygnes	Mound City, Kans.	.83	.82	-- 1936	--	19.67	.05	--	--	--	SCS
	do	do	do	--	--	July 1967	31	11.06	.03	*60	.34	444	
31-49	Pool	Trib. Elk Creek	Circleville, Kans.	.16	.16	Oct. 1958	--	18.07	.39	--	--	--	SCS
	do	do	do	--	--	July 1968	9.75	16.18	.35	*60	1.19	1,555	
31-50	Richter	Trib. Straight Creek	Holton, Kans.	.28	.27	Fall 1957	--	64.36	.80	--	--	--	SCS
	do	do	do	--	--	July 1968	11	59.98	.74	*60	1.47	1,921	
31-51	Reamer	do	do	.23	.23	July 1956	--	31.26	.47	--	--	--	SCS
	do	do	do	--	--	July 1968	12	27.3	.41	*60	1.43	1,869	
31-52	Rogers	Big Sugar	Garrett, Kans.	1.17	1.16	-- 1936	--	22.8	.049	--	--	--	SCS
	do	do	do	--	--	June 1967	31	14.1	.03	67	.24	350	
31-53	Lemon	Trib. of Elm Creek	Parker, Kans.	.19	.19	June 1961	--	6.7	.08	--	--	--	SCS
	do	do	do	--	--	July 1967	6	6.16	.08	60	.47	614	
31-54	Elks Camera Reservoir	Trib. Bull Creek	Gardner, Kans.	.77	.69	July 1960	--	204.3	.607	--	--	--	SCS
	do	do	do	--	--	Sept. 1970	10.2	191.1	.568	*60	1.88	2,457	
31-55	Oberbelman Pond	do	Edgerton, Kans.	.57	.50	Sept. 1960	--	14.883	.061	--	--	--	SCS
	do	do	do	--	--	Sept. 1970	10	11.03	.045	*65	.77	1,090	
31-56	Richmond Lake	Dry Branch	Richmond, Kans.	.86	.84	-- 1955	--	232.86	.68	--	--	--	SCS
	do	do	do	--	--	July 1967	12	222.06	.65	*60	1.07	1,398	
31-57	Hall Pond	Trib. Little Sugar	Farlinville, Kans.	.38	.37	Feb. 1955	--	46.22	.25	--	--	--	SCS
	do	do	do	--	--	July 1967	12	42.87	.24	*60	.76	993	
31-58	Johnson Pond	do	Blue Mound, Kans.	.94	.93	-- 1936	--	24.03	.05	--	--	--	SCS
	do	do	do	--	--	July 1967	31	17.3	.039	*60	.24	313	
SMOKY HILL AND LOWER REPUBLICAN RIVER BASINS													
32-1	Ottawa County State Lake	Sand Creek	Bennington, Kans.	20.47	20.46	-- 1929	--	1,001	--	--	--	--	SCS
	do	do	do	--	--	Apr. 1937	8.0	930	--	--	.438	--	
32-2	Sheridan County State Lake	Saline River	Quinter, Kans.	493	463	Aug. 1937	--	777	--	--	--	--	BR
	do	do	do	--	--	Aug. 1948	10.8	436	--	66.5	.0481	98.6	
32-3a	Kanopolis	Smoky Hill River	Kanopolis, Kans.	7,860	3/2,560	July 1946	--	446,000	--	--	--	--	CE
	do	do	do	--	--	Sept. 1960	14.2	436,320	--	*50.0	.27	294	
32-4	Allington Reservoir	Sicily Creek	Beatrice, Nebr.	.52	.512	-- 1936	--	33.104	--	--	--	--	SCS
	do	do	do	--	--	-- 1956	20	14,704	--	*65	1.77	2,506	
32-5	Barnard Farm Reservoir	Indian Creek	do	.675	.661	Aug. 1947	--	30.5	--	--	--	--	SCS
	do	do	do	--	--	May 1956	8.75	22.22	--	*65	1.400	1,982	
32-6	Evers Reservoir	Trib. of Little Blue River	Hubbell, Nebr.	.173	.171	-- 1937	--	8.058	--	--	--	--	SCS
	do	do	do	--	--	-- 1958	21	2.301	--	*65	1.566	2,217	

32-7	Fling Estate	do	do	.108	.103	--	1945	--	18.606	—	—	—	—	SCS
	do	do	do	—	—	--	1958	13	13.852	—	*65	3.44	4,870	
32-8	Hammire Reservoir	do	Reynolds, Nebr.	—	—	--	1948	—	5.943	—	—	—	--	SCS
	do	do	do	—	—	--	1958	10	3.641	—	*65	2.36	3,624	
32-9	Kapke Reservoir	do	Gladstone, Nebr.	.306	.302	--	1913	--	9.806	—	—	—	—	SCS
	do	do	do	—	--	--	1958	45	5.179	—	*65	.337	477	
32-10	Kuhne Reservoir No. 1	Bloody Run	Virginia, Nebr.	.422	.404	--	1899	—	70.7	—	—	—	—	SCS
	do	do	do	—	--	--	1956	57	30.8	—	*70	1.66	2,531	
32-11	Kuhne Reservoir No. 2	do	do	.102	.099	--	1946	—	9.67	—	—	—	—	SCS
	do	do	do	—	—	--	1956	10	8.06	—	*65	1.58	2,237	
32-12	Omer Reservoir	Trib. of Little Blue River	Gladstone, Nebr.	.292	.283	—	1946	—	5.587	—	—	—	—	SCS
	do	do	do	—	—	—	1958	12	3.735	—	*65	.527	766	
32-13	Peithmann Reservoir	do	Hubbell, Nebr.	.216	.212	—	1950	—	9.934	—	—	—	—	SCS
	do	do	do	—	--	--	1958	8	5.574	—	*65	2.523	3,572	
32-14	Wit Reservoir	do	do	.191	.187	—	1946	—	12.274	—	—	—	—	SCS
	do	do	do	—	—	—	1958	12	6.522	—	*65	2.508	3,551	
32-15a	Woody Hereford Ranch	Unnamed Trib.	Lincoln, Kans.	1.20	1.19	Nov.	1936	—	41.6	—	--	—	—	SCS
	do	do	do	—	—	Sept.	1955	19	23.6	—	*60	.79	1,032	
32-16a	Dougherty	do	Russell, Kans.	.97	.96	Sept.	1947	—	22.5	.435	—	—	—	SCS
	do	do	do	—	—	Sept.	1955	8	16.1	.311	*60	.83	1,085	
32-17	Lost Creek D-1	Trib. of Lost Creek	Lincoln, Kans.	1.56	1.52	Jan.	1957	—	[1] 92.43	--	—	—	—	SCS
	do	do	do	—	—	July	1962	5.5	86.67	--	47.1	.69	708	
32-18	Jepson	Trib. of Spillman Creek	do	1.0	1.0	May	1953	--	[1] 67.73	--	—	—	--	SCS
	do	do	do	—	—	July	1962	9.2	39.44	--	61.2	.90	1,200	
32-19	Wilson Bros.	Trib. of Saline River	do	.22	.21	Sept.	1950	—	[1] 9.51	—	—	—	—	SCS
	do	do	do	—	--	July	1962	11.8	8.28	—	*60	.48	627	
32-20	Zvolanek	do	do	.222	.220	Nov.	1953	—	[1] 16.65	—	—	—	—	SCS
	do	do	do	—	—	July	1962	8.75	15.23	—	70.6	.73	1,122	
32-21	Ekstrom	Trib. of Timber Creek	Vliets, Kans.	.16	.15	July	1956	—	[1] 15.29	—	—	—	—	SCS
	do	do	do	—	—	May	1962	5.8	14.14	—	80.9	1.33	2,344	
32-22	Cornelsen	Trib. of Black Vermillion	do	.125	.120	June	1956	—	[1] 8.16	—	—	—	—	SCS
	do	do	do	—	—	May	1962	5.9	5.84	—	63.6	3.25	4,500	
32-23	Droge	Unnamed Trib.	Bern, Kans.	.35	.34	July	1958	—	[1] 27.30	—	—	—	—	SCS
	do	do	do	—	—	May	1962	3.8	25.45	—	99.4	1.44	1,863	
32-24	Robson	Trib. of Holland Creek	Elmo, Kans.	.156	.152	June	1956	—	[1] 10.51	—	—	—	—	SCS
	do	do	do	—	—	June	1962	6	9.68	—	75.6	.92	1,515	
32-25	Jacobson	Trib. of Turkey Creek	Dayton, Kans.	.211	.206	July	1950	—	11.78	—	--	—	—	SCS
	do	do	do	—	—	June	1962	12	5.16	—	62.9	2.67	3,658	
32-26	Fray	do	Elmo, Kans.	.128	.127	Dec.	1954	—	1.78	—	—	--	—	SCS
	do	do	do	—	—	June	1962	7.6	1.47	—	55.7	.31	376	
32-27	Beck	Trib. of Smoky Hill River	Navarre, Kans.	.560	.544	Oct.	1954	—	4.88	—	—	—	—	SCS
	do	do	do	—	—	July	1962	7.75	2.71	—	53.4	.51	593	
32-28	Dodd	Trib. of Dutch Creek	Centralia, Kans.	.64	.63	Oct.	1953	—	[1] 74.07	—	—	—	—	SCS
	do	do	do	—	—	May	1962	8.6	65.34	—	53.2	1.62	1,878	
32-29	Harlan County	Republican River	Republican City, Nebr.	20,753	9,277	July	1951	—	890,000	—	—	—	—	CE
	do	do	do	—	—	Sept.	1962	11.25	837,900	—	72	.116	182	
32-30	Grant Tosier	Trib. of Saline River	Beverly, Kans.	.99	.96	Mar.	1952	—	[1] 71.9	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1965	13.6	60.9	—	*72	.84	1,317	
32-31	Heikes Pond	Trib. Elk Creek	Lenora, Kans.	1.84	1.83	Oct.	1957	—	32	.466	—	—	—	SCS
	do	do	do	—	—	Aug.	1970	12.8	24.59	.356	*75	.32	523	
32-32	Pinney Pond	Trib. Third Creek	Simpson, Kans.	1.39	1.27	Oct.	1960	—	122.5	1.003	—	—	—	SCS
	do	do	do	—	—	June	1970	9.7	116	.951	*80	.53	923	
32-33	Chrisler Pond	Trib. Saline River	Victoria, Kans.	1.01	.26	Dec.	1956	—	59.66	1.055	—	—	—	SCS
	do	do	do	—	—	July	1970	13.6	56.93	1.02	*60	.77	1,004	
32-34	Chaney Pond	Trib. Dry Creek	Delphos, Kans.	1.08	.92	Dec.	1956	—	108.11	.939	—	—	—	SCS
	do	do	do	—	—	June	1970	13.5	99.11	.862	*60	.72	947	
32-35	Bruna Pond	Trib. Little Blue	Washington, Kans.	1.20	1.16	Apr.	1956	—	86.033	.395	—	—	—	SCS
	do	do	do	—	—	June	1970	13.3	78.19	.36	*75	.51	831	
32-36	Berger Pond	Trib. Buffalo Creek	Randall, Kans.	.59	.57	June	1953	—	22.68	.38	—	—	—	SCS
	do	do	do	—	—	June	1970	17	11.51	.195	*65	1.15	1,632	
32-37	Duvall Pond	Trib. Saline River	Bunker Hill, Kans.	1.77	1.41	Dec.	1960	—	104.86	.855	—	—	—	SCS
	do	do	do	—	—	July	1970	9.6	103.17	.846	*75	.12	204	
32-38	Jensenius Pond	Trib. of Wolf Creek	Prairie View, Kans.	1.31	1.1	Nov.	1954	—	100	1.68	—	—	—	SCS
	do	do	do	—	—	July	1970	15.7	91	1.54	*65	.52	733	
32-39	Jones Pond	Trib. Smoky Hill River	Arnold, Kans.	.93	.92	Dec.	1944	—	23.42	.556	—	—	—	SCS
	do	do	do	—	--	Aug.	1970	25.7	21.25	.506	*80	.09	158	
32-40	King Pond	Trib. Mortimer Creek	Glasco, Kans.	1.03	.57	Nov.	1960	—	47.3	.453	—	—	—	SCS
	do	do	do	—	--	June	1970	9.6	45.3	.431	*65	.36	507	
32-41	Kinney Pond	Trib. Buffalo Creek	Mankato, Kans.	.77	.71	Sept.	1950	—	91.9	1.279	—	—	—	SCS
	do	do	do	—	—	June	1970	19.8	88.4	1.194	*65	.25	348	
32-42	Lee Pond	Trib. Saline River	Tescott, Kans.	.85	.82	Apr.	1952	—	152.4	1.868	—	—	—	SCS
	do	do	do	—	—	June	1970	18.2	146.3	1.784	*55	.42	492	
32-43	Lindsley Pond	Trib. Mill Creek	Morrowville, Kans.	.72	.65	Oct.	1960	--	39.2	.319	—	—	—	SCS
	do	do	do	—	—	June	1970	9.7	35.8	.291	*70	.53	611	
32-44	Lloyd Pond	Trib. Republican River	Scandia, Kans.	.85	.84	July	1932	—	23.15	.193	—	—	—	SCS
	do	do	do	—	—	July	1970	38	8.12	.078	*70	.38	575	
32-45	Lovell Pond	Beaver Creek	Franklin, Nebr.	2.16	2.08	July	1951	—	126.72	.957	—	—	—	SCS
	do	do	do	—	--	July	1970	19	95.86	.728	*65	.78	1,106	
32-46	Mellenkamp Pond	Trib. Saline River	Collyer, Kans.	6.15	6.12	Apr.	1961	—	90.6	.368	—	--	—	SCS
	do	do	do	—	—	Aug.	1970	9.3	79.4	.328	*65	.20	277	
32-47	North Pond	Trib. Smoky Hill River	McCracken, Kans.	2.43	.91	Mar.	1955	—	96.83	.651	—	—	—	SCS
	do	do	do	—	—	July	1970	15.3	91.55	.616	*65	.38	537	
32-48	Raleigh Pond	Trib. Salt Creek	Agenda, Kans.	.90	.80	Mar.	1964	—	81.5	.653	—	—	—	SCS
	do	do	do	—	—	July	1970	6.3	79.4	.635	*60	.42	544	

[1] Water supply pool capacity. Reservoir has greater capacity at spillway crest elevation.
[2] Excludes conservation pool area and terraced area of watershed.
[3] 7,860 prior to closure of Cedar Bluff Dam Sept. 1950.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
SMOKY HILL AND LOWER REPUBLICAN RIVER BASINS (Continued)													
32-49	Sanger Pond	Trib. S. F. Solomon River	Morland, Kans.	2.53	2.32	Mar. 1954	—	332.12	3.519	--	—	—	SCS
	do	do	do	—	—	Aug. 1970	16.4	307.5	3.271	*65	0.65	917	
32-50	Brucine Pond	Trib. Rose Creek	Munden, Kans.	1.61	1.61	July 1954	—	12.896	.058	—	--	—	SCS
	do	do	do	—	—	July 1970	16	6.8	.030	*70	.24	361	
32-51	Schurle Pond	Trib. Mall Creek	Green, Kans.	.73	.67	Nov. 1960	—	127.1	1.088	--	—	—	SCS
	do	do	do	—	—	June 1970	9.6	123.3	1.053	*60	.59	767	
32-52	Mals Pond	Trib. Saline River	Ogallah, Kans.	3.93	3.8	Aug. 1958	—	69.32	.389	--	—	—	SCS
	do	do	do	—	—	Aug. 1970	12	63.64	.357	*60	.12	162	
32-53	Woelhoff Pond	Trib. Five Creek	Morganville, Kans.	.61	.59	June 1954	—	29.05	.331	--	—	--	SCS
	do	do	do	—	—	July 1970	16.1	24.52	.278	*65	.48	680	
32-54	Herington City Lake	Lyons Creek	Herington, Kans.	17.24	16.93	May 1922	—	2,180	.68	—	--	—	SCS
	do	do	do	—	—	May 1966	44	1,455	.65	*70	.96	1,463	
UPPER REPUBLICAN, NORTH PLATTE, RIVER BASINS (FT. LARAMIE TO NORTH PLATTE) AND SOUTH PLATTE RIVER BASIN (SUBLETTE TO NORTH PLATTE)													
33-1	Wallfleet	Medicine Creek	Wallfleet, Nebr.	1/15.00	14.89	Oct. 1931	—	519	—	—	—	—	SCS
	do	do	do	—	--	May 1937	5.6	464	—	*65	.66	934	
33-2	Lockhart Farm Pond	Trib. of N. Platte River	Gering, Nebr.	2/2.564	2.558	Aug. 1939	—	15.64	.229	—	—	—	SCS
	do	do	do	--	—	July 1952	12.9	8.83	.129	57.3	.206	257	
33-3a	Harry Strunk Lake (Medicine Creek Dam)	Medicine Creek	Cambridge, Nebr.	656	653	Aug. 1949	—	92,817	1.691	—	—	—	BR
	do	do	do	—	—	Oct. 1951	2.16	90,920	1.656	71.4	1.34	2,084	
	do	do	do	—	—	Dec. 1962	11.17	88,663	1.615	70.3	.31	475	
33-4a	Flannagin Reservoir	Trib. of Republican River	Bartley, Nebr.	.500	.497	— 1940	—	9.71	—	—	—	--	SCS
	do	do	do	—	—	-- 1956	16	4.89	—	*70	.602	918	
33-5a	Gallatin Reservoir	Trib. of Beaver Creek	Danberry, Nebr.	3.44	3.09	Apr. 1946	—	419.5	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1956	10.4	381.6	—	*70	1.18	1,800	
33-6	Klein Reservoir	Trib. of Republican River	McCook, Nebr.	1.59	1.57	— 1936	—	106.2	—	—	—	—	SCS
	do	do	do	—	—	— 1956	20	56.0	—	*70	1.58	2,609	
33-7	Dempsey Pond	Trib. of East Curtis Creek	Moorefield, Nebr.	*.516	.51	June 1949	—	11.00	—	—	—	—	ARS
	do	do	do	—	—	July 1953	4	10.10	—	—	.447	—	
	do	do	do	—	—	June 1958	4.9	9.12	—	75.6	.392	645	
33-8a	Reichelt Stock Pond	Unnamed	Julesburg, Colo.	.72	.72	Oct. 1950	—	22.12	—	—	--	—	SCS
	do	do	do	—	—	Nov. 1957	7	20.69	—	80.4	.28	490	
33-9	Doshale Pond	Trib. Beaver Creek	Atwood, Kans.	1.41	1.4	Nov. 1948	—	18.19	.968	—	--	—	SCS
	do	do	do	—	—	Aug. 1970	21.8	9.74	.541	*70	.28	422	
33-10	Frickey Pond	Trib. Sappa Creek	Norcatur, Kans.	3.32	3.28	Dec. 1958	—	72.48	.683	—	—	—	SCS
	do	do	do	—	—	July 1970	11.6	63.17	.596	*60	.24	320	
33-11	Walker Pond	Trib. Beaver Creek	Atwood, Kans.	4.78	4.77	Oct. 1948	—	20.96	.329	—	—	—	SCS
	do	do	do	—	—	Aug. 1970	21.8	13.82	.215	*70	.07	105	
33-12	Strout Pond	Trib. Jones Canyon Creek	McDonald, Kans.	.83	.82	Nov. 1958	—	111.25	10.053	—	—	—	SCS
	do	do	do	—	—	July 1970	11.7	102.01	9.274	*70	.96	1,467	
33-13	Franktown-Parker W-1 W'shed	Willow Creek	Castle Rock, Colo.	7.6	7.57	June 1963	—	387	*1.92	—	—	—	SCS
	do	do	do	—	—	Jan. 1967	4	337.4	*1.67	—	1.6	—	
33-14	Bondegard Stock Pond	Sedgewick Draw	Lodgepole, Nebr.	1.5	1.5	— 1952	—	27.68	1.20	—	—	—	SCS
	do	do	do	—	—	Dec. 1967	15	23.88	1.04	*75	.17	277	
NORTH PLATTE RIVER BASIN (ABOVE FT. LARAMIE) SOUTH PLATTER RIVER BASIN (ABOVE SUBLETTE)													
34-1	Castlewood	Cherry Creek	Denver, Colo.	167.2	166.9	— 1890	—	3,834	—	—	—	—	SCS
	do	do	do	—	—	3/Aug. 1933	43	3,126	—	77.5	.099	167	
34-2	Kenwood	do	do	387	386	Mar. 1936	—	9,802	—	—	—	—	SCS
	do	do	do	—	—	June 1938	2.25	9,710	—	75.6	.106	175	
	do	do	do	—	—	June 1939	1.00	9,624	—	—	.741	1,220	
34-3a	Guernsey Reservoir	North Platte River	Guernsey, Wy.	15,004	675	Feb. 1927	—	73,810	—	—	—	—	BR
	do	do	do	—	—	Jan. 1931	3.83	67,840	—	—	.28	—	
	do	do	do	--	—	Jan. 1933	2.00	65,090	—	—	.26	—	
	do	do	do	—	—	Jan. 1935	2.00	62,960	—	--	.20	—	
	do	do	do	—	—	Feb. 1937	2.10	60,930	—	—	.18	--	
	do	do	do	--	—	Feb. 1939	2.00	58,430	—	—	.23	—	
	do	do	do	—	—	Jan. 1941	2.00	56,600	—	—	.17	—	
	do	do	do	—	—	Jan. 1944	3.00	53,180	—	—	.21	—	
	do	do	do	—	—	July 1947	3.90	49,150	—	—	.21	263	
	do	do	do	--	—	June 1957	9.92	44,800	—	60.7	.103	107	
	do	do	do	--	--	Dec. 1966	9.40	4/45,228	.0467	54	—	—	
34-4a	Lake Cheesman	South Platte R. and Goose or Lost Park Cr.	Deckers, Colo.	1,766	1,460	Oct. 1900	—	79,064	.595	—	--	—	BR
	do	do	do	—	--	Sept. 1931	31	77,958	.586	*70	.025	37.2	

34-5	Pathfinder	North Platte River	Alcova, Wy.	10,700	5/3,315	June	1909	—	1,056,300	—	—	—	—	BR
	do	do	do	—	—	July	1950	41.1	1,015,876	—	82.1	7/.090	7/138	
34-6	Seminoe	do	Leo, Wy.	7,348	7,317	—	1939	—	1,020,000	1.198	—	—	—	BR
	do	do	do	—	—	Sept.	1950	11.5	1,012,000	1.169	965	6/.108	6/153	
34-7	Englewood	Little Dry Creek	Littleton, Colo.	9.60	9.25	—	1936	—	1,282.3	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1956	19.5	1,215.2	—	—	.37	—	
34-8a	E-3 Kiowa Creek Watershed	Kiowa Creek	Elbert, Colo.	2.92	2.89	July	1956	—	147.39	*.27	—	—	—	SCS
	do	do	do	—	—	Mar.	1966	10	138.22	*.25	980	.32	597	
34-9	Round Butte	Coal Creek	Wellington, Colo.	11.7	11.6	—	1905	—	831	—	—	—	—	SCS
	do	do	do	—	—	June	1965	60	785	—	69	.07	105	
34-10a	G-51 Kiowa Creek Watershed	Kiowa Creek	Elbert, Colo.	.56	.56	June	1957	—	32.30	*.31	—	—	—	SCS
	do	do	do	—	—	Jan.	1966	9	30.17	*.29	980	.43	769	
34-11	J-33 Kiowa Creek Watershed	do	Eastonville, Colo.	1.07	1.06	July	1956	—	62.55	—	—	—	—	SCS
	do	do	do	—	—	July	1965	9	62.05	—	980	.05	87	
34-12	E-9 Kiowa Creek Watershed	do	Elbert, Colo.	.65	.64	Dec.	1955	—	69.36	—	—	—	—	SCS
	do	do	do	—	—	July	1965	9.5	68.82	—	980	.09	157	
34-13	Slab Canyon CCC	Slab Canyon	Wellington, Colo.	3.15	3.08	July	1937	—	311.4	*1.85	—	—	—	SCS
	do	do	do	—	—	Feb.	1968	30	288.3	*1.72	—	.25	—	
MISSOURI RIVER BASIN (ABOVE BLAIR TO NEBRASKA CITY) PLATTE RIVER BASIN (BELOW NORTH PLATTE)														
35-1	Otto Baak	Trib. of Soldier River	[illegible], Iowa	.199	.197	Sept.	1964	—	9/6.51	*.177	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	4.6	2.28	*.058	56.9	6.42	7,070	
35-2	Fred Brown	Trib. of Willow River	Logan, Iowa	.100	.097	June	1961	—	9/11.09	*.594	—	—	—	SCS
	do	do	do	—	—	May	1969	7.9	4.61	*.230	63.2	9.51	13,080	
35-3	William Rebeck	Trib. of Elkhorn Creek	Elkhorn, Iowa	.208	.206	May	1960	—	9/12.60	*.238	—	—	—	SCS
	do	do	do	—	—	May	1969	9.0	4.51	*.087	56.2	4.43	5,390	
35-4	G. & A. Evers Lower Reservoir	Trib. of Boyer River	Denison, Iowa	.187	.139	Dec.	1958	—	9/5.63	*.138	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	10.3	1.36	*.036	69.8	3.75	5,700	
35-5	G. & A. Evers Upper Reservoir	do	do	.045	.044	Mar.	1959	—	9/1.90	*.158	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	10.1	.22	*.018	71.4	3.77	5,870	
35-6	Charles Pienhold	do	Dunlap, Iowa	.430	.425	May	1965	—	9/12.43	*.123	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	3.9	2.90	*.028	63.1	5.87	8,070	
35-7a	C. V. Good	Trib. of E. Nishnabotna R.	Stennett, Iowa	.081	.079	Dec.	1960	—	14.48	*.762	—	—	—	SCS
	do	do	do	—	—	May	1969	8.4	12.62	*.675	63.9	2.51	3,490	
	do	do	do	—	—	June	1972	3.1	11.98	*.631	57.9	3.43	4,330	
35-8	Otto Goslar	Trib. of Middle Soldier R.	Charter Oak, Iowa	.089	.086	May	1960	—	9/10.18	*.485	—	—	—	SCS
	do	do	do	—	—	Mar.	1969	8.8	8.39	*.375	66.8	2.90	3,730	
35-9	Thomas Rodkin	Trib. of Boyer River	Dow City, Iowa	.130	.127	Aug.	1961	—	9/19.39	*.388	—	—	—	SCS
	do	do	do	—	—	May	1969	10/8.0	.21	*.036	83.2	53.9	97,760	
35-10	Fred Hallrah	Trib. of Willow Creek	Ute, Iowa	.217	.213	Aug.	1964	—	9/14.98	*.365	—	—	—	SCS
	do	do	do	—	—	May	1969	4.6	12.76	*.265	58.3	6.35	8,060	
35-11b	Jones Creek	Jones Creek	Pisgah, Iowa	2.26	2.23	Feb.	1962	—	256.2	*.527	—	—	—	SCS
	do	do	do	—	—	Jan.	1969	6.9	233.8	*.460	67.8	2.11	3,197	
	do	do	do	—	—	Sept.	1970	1.7	231.5	*.479	62.8	2.68	3,620	
	do	do	do	—	—	Jan.	1973	2.3	199.2	*.413	61.6	2.60	3,230	
35-12a	Hans La Fronts	Trib. of Boyer River	Denison, Iowa	.153	.152	May	1962	—	15.28	*.377	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	6.9	10.38	*.392	56.7	4.67	5,767	
	do	do	do	—	—	July	1973	4.2	9.47	*.357	62.0	1.41	1,906	
35-13	Jensen-O'Neil Farm Pond	Trib. of L. Nemaha River	Syracuse, Nebr.	.199	.193	Mar.	1956	—	23.7	*.648	—	—	—	SCS
	do	do	do	—	—	Mar.	1968	12.0	16.8	*.467	56.9	2.97	3,680	
35-14	Peterson Farm Pond	do	do	.075	.074	Oct.	1956	—	2.06	*.158	—	—	—	SCS
	do	do	do	—	—	July	1968	11.75	.16	*.012	59.7	2.19	2,850	
35-15b	Alfred Lage	Trib. of Elk Creek	Aspinwall, Iowa	.184	.182	Aug.	1961	—	11.23	*.339	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	7.8	8.56	*.175	53.2	1.88	2,180	
	do	do	do	—	—	June	1972	3.2	7.14	*.144	51.9	2.42	2,735	
35-16a	Herman Lage	do	do	.038	.036	July	1961	—	12.07	*1.227	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	7.8	10.83	*1.083	56.8	4.417	5,270	
	do	do	do	—	—	June	1972	3.2	8.98	*.898	49.5	16.1	17,358	
35-17a	Howard Matteson	Trib. of Boyer River	Denison, Iowa	.100	.098	July	1964	—	16.44	*.982	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	4.8	12.56	*.735	69.1	8.26	12,431	
	do	do	do	—	—	July	1973	4.3	5.71	*.336	67.1	16.3	30,900	
35-18a	Wilbur Meyer	do	do	.297	.293	Mar.	1964	—	43.80	*.576	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	4.5	37.33	*.491	56.3	5.02	6,160	
	do	do	do	—	—	June	1972	3.2	34.43	*.436	56.1	2.88	3,520	
35-19a	Max Miller No. 1	Trib. of W. Nishnabotna R.	Macedonia, Iowa	.223	.218	Mar.	1961	—	43.84	*.877	—	—	—	SCS
	do	do	do	—	—	May	1969	7.3	35.66	*.720	69.2	5.12	7,380	
	do	do	do	—	—	June	1972	3.1	32.10	*.442	69.7	4.95	7,520	
35-20b	Max Miller No. 5	do	do	.233	.228	Mar.	1961	—	53.19	*1.093	—	—	—	SCS
	do	do	do	—	—	May	1969	7.5	41.96	*.807	72.6	6.58	10,405	
	do	do	do	—	—	June	1972	3.1	41.06	*.790	76.5	1.23	1,998	
35-21a	Harvey Mundt	Trib. of Boyer River	Denison, Iowa	.336	.330	Oct.	1964	—	41.35	*.481	—	—	—	SCS
	do	do	do	—	—	Apr.	1969	4.5	33.08	*.385	56.8	11/3.66	11/6,730	
	do	do	do	—	—	June	1972	3.2	29.32	*.340	55.5	11/3.07	11/6,440	
35-22a	Tracy North	do	Vail, Iowa	.243	.238	Mar.	1959	—	48.84	*1.141	—	—	—	SCS
	do	do	do	—	—	Mar.	1969	9.6	40.04	*.936	52.7	3.86	4,420	
	do	do	do	—	—	July	1973	4.3	37.41	*.893	55.7	2.97	3,120	
35-23	Lake Ericson	Cedar River	Ericson, Nebr.	12/300	41	May	1913	—	1,652	—	—	—	—	BR
	do	do	do	—	—	Apr.	1948	32.9	1,066	—	80	.436	756	
35-24a	Roe Farm Pond	Trib. of Turkey Creek	Dannebrog, Nebr.	.18	.18	July	1947	—	*1.0	*.104	—	—	—	SCS
	do	do	do	—	—	Aug.	1953	5	*.443	*.087	965	.39	552	

1/ Excludes 28 sq. mi. of noncontributing drainage.
2/ Drainage area includes partial sediment trap for 0.133 sq. mi. and is estimated to retain 0.[illegible] ac.-ft. of sediment per year.
3/ Dam failed in 1933; survey made in 1939.
4/ Gain in capacity due to sediments sluiced from dam.
5/ Excludes 7,348 sq. mi. above Seminoe Dam, which was closed in April 1939.
6/ For period April 1939 - July 1950.
7/ For period June 1909 - July 1950.
8/ Below elevation 6,340 which is 17 ft. below spillway crest.
9/ Water supply pool capacity. Reservoir has greater capacity at spillway crest elevation.
10/ Reservoir silted full June 1964.
11/ Includes 0.13 ac.-ft. of sediment above emergency spillway.
12/ Area assumed to contribute surface runoff is 41 mi.²

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
			MISSOURI RIVER BASIN (ABOVE BLAIR TO NEBRASKA CITY) PLATTE RIVER BASIN (BELOW NORTH PLATTE) (Continued)										
35-25	Howe Farm Pond	Trib. of Dead Horse Creek	Loup City, Nebr.	1.80	1.79	Aug. 1948	—	15.6	*.163	—	—	—	SCS
	do	do	do	—	—	Aug. 1953	5	13.9	*.145	*65	.20	283	
35-26	Muller Farm Pond	Trib. of Oak Creek	Farwell, Nebr.	.358	.354	Aug. 1949	—	15.40	*.811	—	—	—	SCS
	do	do	do	—	—	Aug. 1953	4	14.39	*.757	*65	.71	1,005	
35-27	Rusicka Farm Pond	do	do	.27	.26	Aug. 1949	—	30.74	*2.135	—	—	—	SCS
	do	do	do	—	—	Aug. 1953	4	28.03	*1.947	*65	2.62	3,709	
35-28	Brehmer Reservoir	Trib. of L. Nemaha River	Dunbar, Nebr.	.184	.180	— 1952	—	11.78	—	—	—	—	SCS
	do	do	do	—	—	— 1957	5	9.93	—	*65	2.01	2,846	
35-29	Cook Reservoir	Trib. of Papillion Creek	Arlington, Nebr.	.398	.385	— 1934	—	29.4	—	—	—	—	SCS
	do	do	do	—	—	— 1957	23	21.1	—	*65	.921	1,304	
35-30a	Ingwerson Reservoir No. 1	Turkey Creek	Louisville, Nebr.	.211	.209	— 1952	—	12.17	—	—	—	—	SCS
	do	do	do	—	—	— 1957	5	10.19	—	*65	1.89	2,676	
35-31	Ingwerson Reservoir No. 2	do	do	.076	.073	— 1952	—	.72	—	—	—	—	SCS
	do	do	do	—	—	— 1957	5	.19	—	*65	1.43	2,024	
35-32	Ingwerson Reservoir No. 3	do	do	.335	.332	— 1954	—	18.73	—	—	—	—	SCS
	do	do	do	—	—	— 1957	3	17.01	—	*65	1.71	2,421	
35-33	Krase Reservoir	Papillion Creek	Elkhorn, Nebr.	.80	.779	— 1936	—	61.5	—	—	—	—	SCS
	do	do	do	—	—	— 1957	21	11.2	—	*65	2.99	4,233	
35-34	Lugn Reservoir	Unnamed	Douglas, Nebr.	.263	.257	— 1946	—	12.8	—	—	—	—	SCS
	do	do	do	—	—	— 1957	11	4.33	—	*65	2.93	4,148	
35-35	Wiebusr Reservoir	Trib. of L. Nemaha River	Dunbar, Nebr.	.163	.158	— 1949	—	14.48	—	—	—	—	SCS
	do	do	do	—	—	— 1957	8	10.92	—	*65	2.72	3,851	
35-36	O'Brien Reservoir	South Cedar Creek	Manley, Nebr.	.417	.412	— 1937	—	22.09	—	—	—	—	SCS
	do	do	do	—	—	— 1957	20	7.28	—	*65	1.77	2,506	
35-37a	O'Neill Reservoir	Trib. of L. Nemaha River	Syracuse, Nebr.	.140	.130	— 1936	—	35.69	—	—	—	—	SCS
	do	do	do	—	—	— 1957	21	23.98	—	*65	4.29	6,073	
35-38	Pickrell Reservoir No. 1	Russell Creek	Unadilla, Nebr.	.336	.326	— 1949	—	35.76	—	—	—	—	SCS
	do	do	do	—	—	— 1957	8	32.35	—	*65	1.27	1,798	
35-39	Pickrell Reservoir No. 2	do	do	.102	.100	— 1954	—	3.18	—	—	—	—	SCS
	do	do	do	—	—	— 1957	3	2.96	—	*65	.725	1,026	
35-40	Pickrell Reservoir No. 3	do	do	.088	.086	— 1939	—	5.04	—	—	—	—	SCS
	do	do	do	—	—	— 1957	18	1.40	—	*65	2.31	3,270	
35-41	Pickrell Reservoir No. 4	do	do	.114	.113	— 1934	—	2.30	—	—	—	—	SCS
	do	do	do	—	—	— 1957	23	1.60	—	*65	.272	385	
35-42	Pollard Reservoir	Weeping Water Creek	Nehawka, Nebr.	.100	.098	— 1936	—	7.63	—	—	—	—	SCS
	do	do	do	—	—	— 1957	21	4.38	—	*65	1.55	2,194	
35-43	Rose Farm Reservoir	N. Fork Little Fox River	Otoe, Nebr.	.077	.074	— 1948	—	8.12	—	—	—	—	SCS
	do	do	do	—	—	— 1957	9	6.71	—	*65	2.04	2,888	
35-44	Rosher Reservoir	Long Creek	Fort Calhoun, Nebr.	.30	.298	— 1949	—	12.7	—	—	—	—	SCS
	do	do	do	—	—	— 1957	8	4.12	—	*65	3.57	5,054	
35-45b	Male Creek "A"	Trib. of Nishnabotna River	Malvern, Iowa	.180	.177	July 1954	—	43.9	*1.109	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	2.33	42.0	*1.061	73.4	4.63	7,400	
	do	do	do	—	—	Sept. 1957	.92	40.2	*1.015	73.4	11.40	18,200	
	do	do	do	—	—	Oct. 1958	1.08	39.6	*1.000	72.3	3.11	4,900	
	do	do	do	—	—	Jan. 1960	1.33	38.9	*.982	58.7	2.99	3,800	
	do	do	do	—	—	Dec. 1960	.92	36.5	*.922	60.3	14.50	19,000	
	do	do	do	—	—	Feb. 1962	1/1.00	36.0	*.909	2/60.3	2.99	3,940	
	do	do	do	—	—	Jan. 1963	.92	34.7	*.876	69.5	7.85	11,880	
	do	do	do	—	—	Jan. 1964	1.00	3/35.54	*.897	2/60.3	4/-4.66	—	
	do	do	do	—	—	Jan. 1965	1.00	34.45	*.870	2/60.3	6.20	8,140	
	do	do	do	—	—	Jan. 1966	1.00	31.97	*.807	2/60.3	13.99	18,370	
	do	do	do	—	—	Jan. 1967	1.00	32.81	.838	2/60.3	4/-6.22	—	
	do	do	do	—	—	Jan. 1968	1.00	30.88	.780	2/60.3	10.91	14,328	
	do	do	do	—	—	Mar. 1969	1.17	31.37	.792	5/75.5	4/-2.372	—	
35-46b	Male Creek "B"	do	do	.383	.368	Aug. 1954	—	55.3	*.684	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	2.17	52.6	*.651	72.6	3.31	5,200	
	do	do	do	—	—	Sept. 1957	.92	51.8	*.641	69.5	2.55	3,900	
	do	do	do	—	—	Oct. 1958	1.08	50.3	*.623	59.2	3.64	4,700	
	do	do	do	—	—	Jan. 1960	1.33	47.6	*.589	67.2	5.52	8,100	
	do	do	do	—	—	Dec. 1960	.92	47.1	*.583	55.3	1.55	1,900	
	do	do	do	—	—	Feb. 1962	1/1.08	45.1	*.558	2/55.3	5.11	6,150	
	do	do	do	—	—	Jan. 1963	.92	43.5	*.538	62.1	4.73	6,400	
	do	do	do	—	—	Jan. 1964	1.00	44.6	*.552	51.8	4/-2.88	—	
	do	do	do	—	—	Jan. 1965	1.00	42.7	*.528	51.8	4.92	5,550	
	do	do	do	—	—	Jan. 1966	1.00	36.5	*.452	51.8	16.91	19,080	
	do	do	do	—	—	Aug. 1966	.58	39.89	.494	51.8	4/-15.704	—	
	do	do	do	—	—	June 1969	2.75	40.069	.50	5/71.64	4/-.298	—	
35-47a	Male Creek "C"	do	do	6/.916	.323	July 1954	—	76.2	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	2.33	73.8	—	53.9	3.28	3,900	
	do	do	do	—	—	Sept. 1957	.92	69.1	—	66.1	15.50	22,300	

	-do-	-do-	-do-	—	—	Oct. 1958	1.08	67.8	—	59.8	3.90	5,100	
	-do-	-do-	-do-	—	—	Jan. 1960	1.33	66.9	—	61.9	1.98	2,700	
	-do-	-do-	-do-	—	—	Dec. 1960	.92	64.9	—	55.2	6.69	8,000	
	-do-	-do-	-do-	—	—	Feb. 1962	1/1.00	64.1	—	2/55.2	2.60	3,120	
	-do-	-do-	-do-	—	—	Jan. 1963	.92	61.6	—	58.0	8.42	10,640	
	-do-	-do-	-do-	—	—	Jan. 1964	1.00	63.59	—	57.8	4/-6.19	—	
	-do-	-do-	-do-	—	—	Jan. 1965	1.00	59.88	—	65.44	11.49	1,048	
	-do-	-do-	-do-	—	—	Mar. 1969	4.17	57.58	—	5/65.44	1.71	112	
35-49b	Male Creek "F"	Trib. of Male Creek	-do-	.063	.060	Oct. 1955	—	19.4	•1.470	—	—	—	SCS
	-do-	-do-	-do-	—	—	Nov. 1956	1.08	18.6	•1.409	77.2	13.30	22,400	
	-do-	-do-	-do-	—	—	Sept. 1957	.83	17.7	•1.341	57.8	17.90	22,500	
	-do-	-do-	-do-	—	—	Sept. 1958	1.00	17.6	•1.333	72.8	1.50	2,400	
	-do-	-do-	-do-	—	—	Jan. 1960	1.33	17.1	•1.295	44.5	5.83	5,600	
	-do-	-do-	-do-	—	—	Dec. 1960	.92	16.3	•1.235	56.5	15.30	18,900	
	-do-	-do-	-do-	—	—	Feb. 1962	1.17	16.1	•1.220	2/56.5	2.67	3,300	
	-do-	-do-	-do-	—	—	Jan. 1963	.92	15.4	•1.167	60.3	12.17	16,000	
	-do-	-do-	-do-	—	—	Jan. 1964	1.00	—	—	56.0	0	0	
	-do-	-do-	-do-	—	—	Jan. 1965	1.00	14.7	•1.114	54.3	11.43	13,500	
	-do-	-do-	-do-	—	—	Jan. 1966	1.00	13.7	•1.038	54.3	17.32	20,500	
	-do-	-do-	-do-	—	—	Jan. 1967	1.0	14.361	1.088	54.3	4/-7.767	—	
	-do-	-do-	-do-	—	—	Jan. 1968	1.0	13.793	1.045	54.3	9.467	11,196	
	-do-	-do-	-do-	—	—	Feb. 1969	1.08	13.752	1.042	5/69.5	.65	30,756	
35-49b	Male Creek "E"	-do-	-do-	.019	.796	Oct. 1955	—	103	•.595	—	—	—	SCS
	-do-	-do-	-do-	—	—	Oct. 1956	1.00	100	•.578	66.4	4.17	6,000	
	-do-	-do-	-do-	—	—	Sept. 1957	.92	97.4	•.563	64.4	3.98	5,600	
	-do-	-do-	-do-	—	—	Sept. 1958	1.00	97.2	•.562	64.8	.40	600	
	-do-	-do-	-do-	—	—	Jan. 1960	1.33	94.6	•.547	55.6	2.39	2,900	
	-do-	-do-	-do-	—	—	Dec. 1960	.92	93.2	•.539	55.7	1.93	2,300	
	-do-	-do-	-do-	—	—	Feb. 1962	1.17	90.8	•.525	2/55.7	2.61	3,200	
	-do-	-do-	-do-	—	—	Jan. 1963	.92	88.7	•.513	59.4	4.21	5,400	
	-do-	-do-	-do-	—	—	Jan. 1964	1.00	—	—	51.1	4/-2.02	—	
	-do-	-do-	-do-	—	—	Jan. 1965	1.00	86.0	•.497	69.9	5.46	5,900	
	-do-	-do-	-do-	—	—	Jan. 1966	1.00	80.5	•.465	69.9	6.86	7,500	
	-do-	-do-	-do-	—	—	Feb. 1969	1.08	73.867	.423	5/66.29	1.055	13,419	
35-50	Miles Wallace Pond	Platte	Cozad, Nebr.	.81	.81	— 1939	—	2/1.61	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Sept. 1964	25	.72	—	106	.05	113	
35-51	Gayle Miller Pond	-do-	-do-	.94	.94	— 1948	—	16.18	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Sept. 1964	16	13.06	—	70	.21	320	
35-52	Kenneth Smith Pond	-do-	-do-	.49	.49	— 1940	—	5.97	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Oct. 1964	24	4.99	—	95	.08	166	
35-53	Wayne Bartleff Pond	-do-	-do-	1.13	1.13	— 1940	—	15.7	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Oct. 1964	24	12.7	—	95	.11	228	
35-54	Oak-Middle Creek Watershed Site 67-4	North Platte	Dwight, Nebr.	.89	.89	Jan. 1958	—	175.7	—	—	—	—	SCS
	-do-	-do-	-do-	—	—	Dec. 1964	7	140.8	—	66	5.61	8,064	
			RIVER BASIN (NIOBRARA TO ABOVE BLAIR) JAMES AND BIG SIOUX RIVER BASINS										
36-1	Split Rock	Trib. of Big Sioux River	Ihlen, Minn.	42.3	42.1	July 1938	—	899.0	•.314	—	—	—	SCS
	-do-	-do-	-do-	—	—	June 1949	10.9	692.1	•.242	42.8	.462	631	
36-2a	C. A. Stiles	Unnamed	Washta, Iowa	.593	.572	Dec. 1940	—	78.0	•.394	—	—	—	SCS
	-do-	-do-	-do-	—	—	Mar. 1949	8.3	70.7	•.347	46.9	1.54	1,580	
	-do-	-do-	-do-	—	—	Sept. 1950	1.5	69.1	•.335	*57.8	1.82	2,300	
	-do-	-do-	-do-	—	—	Feb. 1953	2.4	67.7	•.326	57.8	.98	1,240	
36-3	Farmers' Ditch Old Desilting Basin	Farmers' Ditch	Bronson, Iowa	22.9	21.4	Apr. 1942	—	8/874	•.178	—	—	—	SCS
	-do-	-do-	-do-	—	—	Feb. 1965	3.8	275	•.073	68.3	4.91	7,300	
36-4	Strunk Farm Pond	Trib. of Clay Creek	Mayfield, S. Dak.	.408	.407	July 1947	—	4.09	•.157	—	—	—	SCS
	-do-	-do-	-do-	—	—	July 1953	6	3.37	•.129	*65	.30	411	
36-5	Brodersen Farm Pond	-do-	Volin, S. Dak.	2.46	2.45	July 1952	—	25.19	•.160	—	—	—	SCS
	-do-	-do-	-do-	—	—	July 1953	1	20.10	•.128	*55	1.04	1,246	
36-6	Masters Upper Reservoir	Unnamed	Mapleton, Iowa	.179	.166	Dec. 1949	—	37.95	•.949	—	—	—	SCS
	-do-	-do-	-do-	—	—	Sept. 1950	.79	9/38.20	•.955	—	—	—	
	-do-	-do-	-do-	—	—	Aug. 1951	.87	35.25	•.881	*77.7	20.1	34,015	
	-do-	-do-	-do-	—	—	Apr. 1952	.73	34.80	•.870	*77.7	3.67	6,211	
	-do-	-do-	-do-	—	—	Nov. 1952	.60	34.80	•.870	77.7	—	—	
36-7	Wepper Main	-do-	-do-	.196	.186	Mar. 1949	—	38.1	•.866	—	—	—	SCS
	-do-	-do-	-do-	—	—	July 1950	1.37	37.8	•.859	*76.1	1.25	2,070	
	-do-	-do-	-do-	—	—	[illegible] 1951	1.01	34.4	•.782	*76.1	17.96	29,768	
	-do-	-do-	-do-	—	—	Nov. 1952	1.32	34.4	•.782	76.1	—	—	
36-8	Wepper Southwest	-do-	-do-	.075	.069	Mar. 1949	—	8.45	•.497	—	—	—	SCS
	-do-	-do-	-do-	—	—	Aug. 1950	1.42	8.45	•.497	*72.7	0	0	
	-do-	-do-	-do-	—	—	Aug. 1951	.98	7.88	•.464	*72.7	8.41	13,319	
	-do-	-do-	-do-	—	—	Nov. 1952	1.30	7.88	•.464	72.7	0	0	

1/ Adjusted to correct previous years error.
2/ Based on December 1960 sample.
3/ Pond dry when surveyed.
4/ Minus (-) indicates scour or compaction. (treated as negative sediment).
5/ Weight determined by gamma probe.

6/ Includes upstream structures.
7/ Water supply pool capacity. Reservoir capacity is greater at spillway crest elevation.
8/ Conservation pool capacity. Flood pool capacity is 1,952 ac.-ft.
9/ Increase in capacity in 1950 was due to settlement of dam.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
RIVER BASIN (NIOBRARA TO ABOVE BLAIR) JAMES AND BIG SIOUX RIVER BASINS (Continued)													
36-9	Theobold Main	Unnamed	Anthon, Iowa	.483	.442	June 1949	—	103.2	*1.053	—	—	—	SCS
	do	do	do	—	—	Aug. 1950	1.15	94.0	*.959	*72.3	18.1	28,502	
	do	do	do	—	—	May 1951	.77	93.5	*.954	*72.3	1.36	2,142	
	do	do	do	—	—	Oct. 1952	1.38	89.2	*.910	72.3	7.13	11,228	
36-10	Theobold Lateral C.	do	do	.250	.236	Nov. 1948	—	37.5	*.735	—	—	—	SCS
	do	do	do	—	—	July 1950	1.70	34.5	*.676	*67.9	7.65	11,313	
	do	do	do	—	—	May 1951	.83	34.3	*.673	*67.9	1.08	1,597	
	do	do	do	—	—	May 1952	.96	33.5	*.657	67.9	3.60	5,324	
36-11	Theobold Lateral D.	do	do	.098	.089	Nov. 1948	—	19.5	*.975	—	—	—	SCS
	do	do	do	—	—	July 1950	1.71	18.9	*.945	*73.1	3.63	5,780	
	do	do	do	—	—	May 1951	.82	18.7	*.935	*73.1	2.86	6,560	
	do	do	do	—	—	Oct. 1952	1.42	18.6	*.930	73.1	.72	1,146	
36-12a	Mortenson	do	Cherokee, Iowa	1.30	1.37	Oct. 1950	—	229.0	*.718	—	—	—	SCS
36-13	Bartlett	Green Creek	Alcester, S. Dak.	.234	.234	Nov. 1936	—	12.84	1.035	—	—	—	SCS
	do	do	do	—	—	Nov. 1955	19	6.86	.553	77.0	1.35	2,264	
36-14b	Lake Mitchell	Firesteel Creek	Mitchell, S. Dak.	584	496	Oct. 1928	—	10,943	.69	—	—	—	SCS
	do	do	do	—	—	July 1948	19.8	10,380	.47	*46.79	.057	58	
	do	do	do	—	—	Aug. 1958	10.0	[illegible]	.44	*46.79	.117	119	
	do	do	do	—	—	July 1969	11.0	9,235	.42	65.47	.103	231	
36-15	Salem Dam	Silver Creek	Sioux Falls, S. Dak.	1,150	1,150	Aug. 1950	—	12.79	.206	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	5.0	8.16	.132	*60	.80	1,045.44	
36-16	Scott No. 2	Scott Creek	Alcester, S. Dak.	.152	.152	Oct. 1936	—	7.36	.909	—	—	—	SCS
	do	do	do	—	—	Apr. 1955	18.5	3.14	.388	56.4	1.52	1,867.2	
36-17	Lake Vermillion	Vermillion	Montrose, S. Dak.	402.9	402.0	Mar. 1959	—	5,173.7	.297	—	—	—	SCS
	do	do	do	—	—	June 1964	5.25	4,927.5	.283	35	.117	89	
36-18	Vermillion Watershed No. A	Trib. of Vermillion	Salem, S. Dak.	.075	.075	Aug. 1955	—	3.20	1.000	—	—	—	SCS
	do	do	do	—	—	Nov. 1965	10.3	2.67	.834	*90	.68	760	
36-19	Vermillion Watershed No. B	do	do	.239	.239	Oct. 1950	—	6.48	.639	—	—	—	SCS
	do	do	do	—	—	Nov. 1963	13	5.06	.691	*90	.40	435	
36-20	Lake Okabena	Trib. of Okabena Creek	Worthington, Minn.	17.60	16.29	— *1897	—	5,183	2.234	—	—	—	SCS
	do	do	do	—	—	Mar. 1963	65	1/5,100	2.198	26	.87	492	
36-21a	Scott Creek #11	Scott Creek	Alcester, S. Dak.	1.85	1.45	Oct. 1954	—	196.64	2.55	—	—	—	SCS
	do	do	do	—	—	Apr. 1965	10.5	192.7	2.90	*65	.26	368	
	do	do	do	—	—	May 1970	5.1	179.75	2.33	—	1.785	2,527	
36-22	Richmond Lake	Foot Creek	Aberdeen, S. Dak.	82	73.5	Jan. 1937	—	9,880.9	7.53	—	—	—	SCS
	do	do	do	—	—	Sept. 1969	32.75	8,971.08	6.84	51.8	.378	426	
MISSOURI RIVER BASIN (ABOVE PIERRE TO NIOBRARA) Niobrara and White River Basins													
77-1a	Elkins Stock Pond No. 1	Br. of Prosemman Creek	Hayes, S. Dak.	.38	.37	May 1907	—	18.61	—	—	—	—	SCS
	do	do	do	—	—	June 1937	30	15.78	—	41.3	.16	144	
77-2	Elkins Stock Pond No. 2	do	do	.33	.33	May 1911	—	4.34	—	—	—	—	SCS
	do	do	do	—	—	June 1937	26.0	3.18	—	36.6	.136	108	
77-3	Land Utilization Project No. 226-1.	Trib. of Bad River	Pierre, S. Dak.	.203	.197	Mar. 1936	—	16.7	—	—	—	—	SCS
	do	do	do	—	—	July 1945	9.3	15.2	—	—	.822	—	
77-4	Land Utilization Project No. 226-2.	Trib. of Missouri River	do	.995	.981	Mar. 1936	—	34.0	—	—	—	—	SCS
	do	do	do	—	—	July 1945	9.3	29.0	—	—	.458	—	
77-5	Land Utilization Project No. 226-4.	Trib. of Bad River	do	.768	.762	May 1936	—	13.6	—	—	—	—	SCS
	do	do	do	—	—	July 1945	9.2	9.9	—	—	.539	—	
77-6	Land Utilization Project No. 226-6.	Trib. of Missouri River	do	2,555	2,542	Apr. 1936	—	31.8	—	—	—	—	SCS
	do	do	do	—	—	July 1945	9.3	25.1	—	—	.285	—	
77-7	Land Utilization Project No. 226-13.	Trib. of Bad River	do	.166	.163	Oct. 1936	—	9.1	—	—	—	—	SCS
	do	do	do	—	—	July 1945	8.7	8.3	—	—	.521	—	
77-8	Land Utilization Project No. 226-21.	Trib. of Missouri River	do	.245	.234	Oct. 1936	—	28.9	—	—	—	—	SCS
	do	do	do	—	—	July 1945	8.7	26.1	—	—	1.309	—	
77-9	Land Utilization Project No. 226-22.	Trib. of Bad River	do	.514	.511	Nov. 1936	—	9.2	—	—	—	—	SCS
	do	do	do	—	—	July 1945	8.7	8.3	—	—	.200	—	

37-10	Land Utilization Project No. 226-25.	Trib. of Missouri River	---do---	.147	.144	Nov.	1937	—	9.3	—	—	—	—	SCS
	---do---	---do---	---do---	--	—	July	1945	7.7	8.4	--	—	.799	—	
37-11	Land Utilization Project No. 226-31.	---do---	---do---	.225	.220	Mar.	1937	—	13.9	--	—	—	—	SCS
	---do---	---do---	---do---	--	--	July	1945	8.3	12.3	—	—	.859	—	
37-12	Land Utilization Project No. 226-32.	---do---	---do---	.477	.472	Mar.	1937	--	14.1	—	—	—	—	SCS
	---do---	---do---	---do---	—	--	July	1945	8.3	12.1	—	—	.508	—	
37-13	Land Utilization Project No. 226-34.	---do---	---do---	1.222	1.209	June	1937	—	44.3	—	—	—	—	SCS
	---do---	---do---	---do---	--	--	July	1945	8.1	40.0	--	—	.443	—	
37-14	Land Utilization Project No. 226-35.	---do---	---do---	.508	.502	May	1938	—	18.4	—	—	--	—	SCS
	---do---	---do---	---do---	--	—	July	1945	7.2	16.1	—	--	.631	—	
37-15	Land Utilization Project No. 243-1.	---do---	---do---	.108	.106	Nov.	1937	--	2.7	—	—	—	—	SCS
	---do---	---do---	---do---	--	--	July	1945	7.7	2.0	--	--	.811	—	
37-16	Land Utilization Project No. 243-2.	Unnamed Stream (interior drainage)	---do---	.134	.131	Nov.	1937	--	5.2	--	--	—	—	SCS
	---do---	---do---	---do---	—	--	July	1945	7.7	3.0	—	--	2.206	—	
37-17	Land Utilization Project No. 243-5.	Trib. of Missouri River	---do---	.072	.070	Nov.	1937	--	2.6	—	—	—	—	SCS
	---do---	---do---	---do---	--	--	July	1945	7.7	2.2	—	--	.700	—	
37-18	Land Utilization Project No. 243-6.	Trib. of Bad River	---do---	.117	.116	Nov.	1937	—	3.2	—	—	—	—	SCS
	---do---	---do---	---do---	--	--	July	1945	7.7	2.8	—	—	.474	—	
37-19	Land Utilization Project No. 243-10.	Trib. of Missouri River	---do---	.533	.532	June	1938	—	3.7	—	—	—	--	SCS
	---do---	---do---	---do---	--	—	July	1945	7.1	2.9	--	--	.222	—	
37-20	Land Utilization Project No. 243-11.	---do---	---do---	.339	.338	July	1938	--	4.5	—	—	—	--	SCS
	---do---	---do---	---do---	--	—	July	1945	7.0	3.9	--	—	.266	—	
37-21	Harris Reservoir North	Unnamed	Gordon, Nebr.	.577	.573	May	1947	—	7.3	—	—	—	—	SCS
	---do---	---do---	---do---	--	--	Nov.	1956	9.5	5.57	—	*70	.315	480	
37-22	Harris Reservoir South	---do---	---do---	11.9	11.85	May	1947	—	18.64	—	—	—	—	SCS
	---do---	---do---	---do---	--	—	Nov.	1956	9.5	15.77	—	*70	.025	38	
37-23	Johnson Reservoir	---do---	---do---	.856	.849	—	1966	--	16.25	—	—	--	—	SCS
	---do---	---do---	---do---	--	—	Nov.	1956	10.3	12.39	—	*70	.435	663	
37-24a	Lake Dante	Trib. of Choteau Creek	Wagner, S. Dak.	2.89	2.89	Nov.	1937	—	260.73	.352	—	—	--	SCS
	---do---	---do---	---do---	—	—	Oct.	1955	17.9	230.95	.312	*60	.578	756	
37-25	Rogers	Trib. of Missouri River	---do---	10.3	10.3	July	1937	—	231.0	.840	—	--	—	SCS
	---do---	---do---	---do---	—	--	July	1965	28	200.32	.728	50	.107	115	

MISSOURI RIVER BASIN (MOBRIDGE TO ABOVE PIERRE)
Cheyenne and Belle Fourche River Basins

38-1	Johnson's Stock Pond	Trib. of L. Cheyenne River	Gettysburg, S. Dak.	.191	.188	—	1912	—	2.56	—	—	—	--	SCS
	---do---	---do---	---do---	--	—	June	1937	25.0	1.85	—	98.1	.16	202	
38-2	Bartel Stock Pond	Little Cheyenne Creek	---do---	.609	.606	—	1908	--	4.30	—	--	—	—	SCS
	---do---	---do---	---do---	--	--	June	1937	29.0	2.80	—	93.6	.08	93.4	
38-3a	W-14 (Anderson)	Trib. of Fourmile Creek	Vale, S. Dak.	.054	.054	Nov.	1956	—	5.60	1.42	--	—	—	ARS
	---do---	---do---	---do---	—	--	Oct.	1958	1.9	5.14	1.30	70	4.48	6,708	
	---do---	---do---	---do---	—	--	Dec.	1962	4.2	4.51	1.14	70	2.78	4,158	
	---do---	---do---	---do---	--	—	Apr.	1967	4.3	4.36	1.11	70	.65	967	
38-4a	W-9 ([illegible])	Sulphur Creek	Sulphur, S. Dak.	1.27	1.27	Nov.	1951	—	350.9	10.35	--	—	—	ARS
	---do---	---do---	---do---	--	--	June	1961	9.6	334	9.85	84	1.38	2,525	
	---do---	---do---	---do---	--	—	June	1969	8.0	315.3	9.3	84	1.84	3,367	
38-5	Angostura Reservoir	Cheyenne River	Hot Springs, S. Dak.	9,100	9,093	Oct.	1949	—	159,919	.866	—	—	—	BR
	---do---	---do---	---do---	--	—	Sept.	1965	16	138,761	.752	56.4	.145	178	
38-6	Sturgis Watershed No. 1	Alkali Creek	Sturgis, S. Dak.	.339	.339	Oct.	1965	—	--	—	—	—	—	FS
	---do---	---do---	---do---	—	--	Oct.	1966	1.0	—	—	92.2	2/--	.019	
	---do---	---do---	---do---	—	--	Oct.	1967	1.0	—	--	92.2	2/--	.687	
	---do---	---do---	---do---	--	--	Oct.	1968	1.0	—	--	92.2	2/—	.044	
	---do---	---do---	---do---	—	—	Oct.	1969	1.0	—	--	92.2	2/--	.252	
	---do---	---do---	---do---	—	--	Oct.	1970	1.0	--	--	92.2	2/—	.495	
38-7	Sturgis Watershed No. 2	---do---	---do---	.139	.139	Oct.	1965	--	--	--	--	--	—	FS
	---do---	---do---	---do---	—	--	Oct.	1966	1.0	—	--	92.2	2/—	.05	
	---do---	---do---	---do---	--	--	Oct.	1967	1.0	—	—	92.2	.001	2,248	
	---do---	---do---	---do---	—	--	Oct.	1968	1.0	--	--	92.2	2/--	.06	
	---do---	---do---	---do---	--	—	Oct.	1969	1.0	—	-	92.2	2/--	.036	
	---do---	---do---	---do---	--	--	Oct.	1970	1.0	--	--	92.2	.004	8,705	
38-8	Sturgis Watershed No. 3	---do---	---do---	.297	.297	Oct.	1965	—	—	—	--	--	—	FS
	---do---	---do---	---do---	—	--	Oct.	1966	1.0	--	—	92.2	2/—	.106	
	---do---	---do---	---do---	--	--	Oct.	1967	1.0	—	--	92.2	2/--	.406	
	---do---	---do---	---do---	--	--	Oct.	1968	1.0	--	--	92.2	2/—	.034	
	---do---	---do---	---do---	--	—	Oct.	1969	1.0	—	--	92.2	2/--	.022	
	---do---	---do---	---do---	—	—	Oct.	1970	1.0	—	--	92.2	.001	2,438	
38-9	Canyon Lake	Rapid Creek	Rapid City, S. Dak.	385	3/66.35	Sept.	1933	--	300.77	.011	—	—	—	SCS
	---do---	---do---	---do---	--	--	Oct.	1970	37	221.75	.008	65	4/.032	4/50	

1/ 837 ac.-ft. of storage created by dredging.
2/ Less than .001. Material removed from Weir Pond facility periodically.
3/ Pactola Reservoir controls about 120 sq. mi.
4/ 9.9 ac.-ft. sediment, removed in 1956, not included.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
MISSOURI RIVER BASIN (MOBRIDGE TO ABOVE PIERRE) Cheyenne and Belle Fourche River Basins (Continued)													
38-10	Barrel Detention Dam	Unnamed	New Castle, Wy.	6.15	4.83	Aug. 1968	--	[illegible]54.6	*6.[illegible]	--	—	—	SCS
	do	do	do	—	—	Dec. 1970	2.25	432.4	*6.7	86	1.49	2,799	
38-11	New Underwood Reservoir	do	New Underwood, S. Dak.	2.97	2.94	-- 1935	—	138.5	—	—	—	—	SCS
	do	do	do	—	--	Aug. 1970	35	120.2	--	*60	.177	231	
MISSOURI RIVER BASIN (WILLISTON TO MOBRIDGE) Moreau, Grand, Cannonball, Heart, and Little Missouri River Basins													
39-1	Frederick Stock Dam	Louse Creek	Flasher, N. Dak.	1.17	1.17	-- 1935	—	1.06	*.021	—	—	—	SCS
	do	do	do	—	--	Aug. 1956	21	.864	*.017	*35	.00797	6.07	
39-2a	Middlewood Lake	Middlewood Creek	Selby, S. Dak.	31.8	27.2	May 1926	—	1/207.78	.549	—	—	--	SCS
	do	do	do	--	--	Sept. 1959	33.3	165.70	.438	55	.047	56	
39-3	Kambisch Reservoir	Trib. of Moreau	Sorum, S. Dak.	2.20	1.97	Aug. 1924	--	389.80	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1964	40	380.75	--	*60	.12	156.8	
39-4	Clark Reservoir	do	do	3.56	2.56	Aug. 1949	—	62.00	—	—	--	--	SCS
	do	do	do	—	—	Aug. 1964	15	56.15	—	*60	.15	196	
39-5	Menzer Reservoir	Trib. of Grand	Lemmon, S. Dak.	.493	.493	Aug. 1951	--	35.96	3.182	—	—	--	SCS
	do	do	do	—	--	Aug. 1964	13	33.96	3.005	*60	.30	392	
39-6	Cole Reservoir	do	Bison, S. Dak.	4.66	2.21	Aug. 1937	—	161.1	—	--	—	—	SCS
	do	do	do	--	--	Aug. 1964	27	144.01	—	*60	.29	379	
39-7	Van Oosting Dam	Trib. of Missouri River	Hensler, N. Dak.	1.78	1.76	Apr. 1950	--	171.5	*3.618	—	--	--	SCS
	do	do	do	--	--	Oct. 1964	14.5	167.0	*3.523	60.4	2/.176	2/[illegible]1.5	
39-8	Battle Creek Detention Dam	Battle Creek	Hulett, Wy.	18.44	18.44	Nov. 1967	--	620.1	*.63	—	—	--	SCS
	do	do	do	--	--	Sept. 1970	2.83	614.7	*.62	71.4	.104	161.8	
MISSOURI RIVER BASIN (ZORTMAN TO WILLISTON) Milk and Musselshell River Basins													
40-1	Yellow Water	Yellow Water Creek	Winnett, Mont.	55	54	June 1938	—	4,796	--	--	--	—	SCS
	do	do	do	—	--	Sept. 1948	10.3	4,616	--	*32	.32	224	
40-2	Fort Peck	Missouri River	Fort Peck, Mont.	57,725	3/--	Oct. 1937	--	19,557,492	—	—	—	—	CE
	do	do	do	—	—	June 1950	12.67	19,233,686	—	56.7	.65	803	
	do	do	do	—	--	Sept. 1952	2.25	19,186,698	—	57.4	.53	724	
	do	do	do	--	—	June 1954	1.75	19,164,369	—	57.9	.33	471	
	do	do	do	--	--	May 1958	3.92	19,162,468	--	58.8	.013	75	
	do	do	do	—	—	June 1961	3.08	19,138,511	--	59.4	.22	338	
MISSOURI RIVER BASIN (ABOVE ZORTMAN)													
41-1	Anderson Reservoir	Trib. of Pondera Creek	Conrad, Mont.	.156	.156	— 1916	—	9.27	—	--	—	--	SCS
	do	do	do	--	—	Oct. 1955	39	8.44	--	*60	.136	183	
41-2a	Kropp	do	do	.625	.625	-- 1900	—	4.70	—	—	—	—	SCS
	do	do	do	--	—	Oct. 1955	55	3.84	--	*60	.025	33	
41-3	Walston	do	do	2.96	2.96	-- 1915	—	66.13	--	—	—	—	SCS
	do	do	do	—	--	Oct. 1955	40	51.71	--	*60	.122	166	
LOWER YELLOWSTONE RIVER BASIN Tongue and Powder River Basins													
42-1a	Baker Lake	Sandstone Creek	Baker, Mont.	5.20	5.01	May 1908	—	756	3.40	—	--	—	SCS
	do	do	do	—	—	May 1937	29.1	502	2.26	39	1.74	1,478	
	do	do	do	—	—	May 1955	18.0	393	1.77	45	1.21	1,553	
	do	do	do	--	--	July 1970	15.2	235	1.06	40	2.08	1,288	
42-2	Tongue River	Tongue River	Decker, Mont.	1,740	1,734.5	May 1939	—	72,510	.248	—	--	—	BR
	do	do	do	--	--	Oct. 1948	9.42	69,439	.237	70.5	.188	288.7	
42-3	Herzog Reservoir	Dry Creek	Miles City, Mont.	6.92	6.92	— 1941	--	300	4.05	—	—	—	SCS
	do	do	do	—	--	-- 1969	28	222	3.0	70	.403	614	

UPPER YELLOWSTONE RIVER BASIN

43-1b	Buffalo Bill	Shoshone River	Cody, Wy.	1,470	1,470	May	1910	—	455,838	.492	—	—	—	BR
	do	do	do	—	—	—	1941	31.7	439,851	.476	—	.34	—	
	do	do	do	—	—	—	1958	17.0	421,333	.455	—	.62	—	
43-2	Big Gin	Trib. of Fifteenmile Creek	Worland, Wy.	.942	.918	Oct.	1954	—	99.2	3.906	—	—	—	GS
	do	do	do	—	—	Oct.	1955	1	98.1	3.862	—	1.2	—	
	do	do	do	—	—	Oct.	1958	3	96.0	3.780	—	.8	—	
	do	do	do	—	—	Oct.	1961	3	93.2	3.669	—	1.0	—	
43-3	Fraser Draw	Fraser Draw	Moneta, Wy.	27.4	27.4	Oct.	1954	—	90.2	1.797	—	—	—	GS
	do	do	do	—	—	Oct.	1958	4	87.7	1.747	—	.02	—	
	do	do	do	—	—	Nov.	1960	2	83.3	1.659	—	.08	—	
43-4	East Fork	Graham Draw	do	.81	.81	June	1949	—	12.30	4.241	—	—	—	GS
	do	do	do	—	—	Nov.	1949	.42	11.73	4.045	—	1.68	—	
	do	do	do	—	—	May	1952	2.54	11.01	3.797	—	.35	—	
	do	do	do	—	—	Oct.	1955	3.42	10.83	3.734	—	.06	—	
	do	do	do	—	—	Oct.	1957	2.00	10.61	3.659	—	.14	—	
	do	do	do	—	—	Oct.	1960	3.00	10.58	3.648	—	.01	—	
43-5	West Fork	do	do	.38	.38	July	1948	—	3.13	3.817	—	—	—	GS
	do	do	do	—	—	Nov.	1949	1.25	2.94	3.585	—	.39	—	
	do	do	do	—	—	May	1952	2.54	2.54	3.098	—	.42	—	
	do	do	do	—	—	Oct.	1955	3.42	2.62	3.195	—	0	—	
	do	do	do	—	—	Oct.	1957	2.00	2.59	3.159	—	.05	—	
	do	do	do	—	—	Oct.	1960	3.00	2.47	3.012	—	.11	—	
43-6	Red Spires	Rock Waterhole Creek	Worland, Wy.	5.24	5.20	Oct.	1954	—	193.4	1.098	—	—	—	GS
	do	do	do	—	—	Oct.	1955	1	191.3	1.086	—	.40	—	
	do	do	do	—	—	Oct.	1958	3	176.1	1.000	—	.98	—	
	do	do	do	—	—	Oct.	1961	3	154.5	.877	—	1.38	—	
43-7	Boysen	Wind River	Thermopolis, Wy.	7,700	7,670	Oct.	1951	—	819,132	.625	—	—	—	BR
	do	do	do	—	—	Aug.	1964	12.8	802,004	.612	83	.17	307	

ARKANSAS RIVER BASIN (VAN BUREN TO LITTLE ROCK) WHITE RIVER BASIN

44-1a	Lake Bennett	East Fork Creek	Conway, Ark.	4.16	4.11	June	1935	—	496	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1935	0.4	490	—	—	2.43	—	
	do	do	do	—	—	Nov.	1946	11.0	481	.130	—	.20	—	
44-2	Lake Booneville	Trib. of Petit Jean Creek	Booneville, Ark.	2.60	2.57	Mar.	1929	—	289	.127	—	—	—	SCS
	do	do	do	—	—	Nov.	1935	6.75	282	—	—	.455	—	
44-3	Lake Fort Smith	Jack and Jones Creeks	Mountainburg, Ark.	65	64	Feb.	1936	—	*13,810	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1940	4.2	13,727	—	—	.31	—	
44-4	Lake Bailey	Cedar Creek	Morrilton, Ark.	15.2	15	Sept.	1937	—	629	—	—	—	—	SCS
	do	do	do	—	—	May	1940	2.7	602	—	—	.66	—	
44-5	Lake Taneycomo	White River	Branson, Mo.	4,610	4,606	Mar.	1913	—	43,980	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1935	22.4	23,714	—	—	.196	—	
44-6	Nimrod	Fourche La Fave River	Nimrod, Ark.	680	652	May	1942	—	336,000	.532	—	—	—	CE
	do	do	do	—	—	Apr.	1950	7.9	4/336,000	.532	—	4/—	—	
44-7	Norfolk	North Fork River	Norfork, Ark.	1,806	1,772	June	1943	—	1,560,900	1.138	—	—	—	CE
	do	do	do	—	—	May	1950	6.9	5/1,560,500	1.138	—	5/—	—	
44-8	Cove Lake	Arkansas River Trib.	Paris, Ark.	10.90	10.66	May	1938	—	2,206	*.298	—	—	—	SCS
	do	do	do	—	—	Dec.	1953	15.5	2,141	*.290	—	.39	—	
44-9	Charleston Lake	do	Charleston, Ark.	1.03	.93	Apr.	1937	—	325	*.455	—	—	—	SCS
	do	do	do	—	—	Dec.	1953	16.66	264	*.370	—	3.94	—	
44-10	Six Mile Creek No. 2	Shaver Creek	Caulksville, Ark.	5.38	5.26	Oct.	1954	—	6/1,613.93	.469	—	—	—	SCS
	do	do	do	—	—	July	1961	6.67	6/1,608.15	.467	—	6/.17	—	
	do	do	do	—	—	Oct.	1954	—	7/309.52	.090	—	—	—	
	do	do	do	—	—	July	1961	6.67	7/301.02	.087	—	7/.24	—	
44-11	Six Mile Creek No. 5	Little Caney Creek	do	1.90	1.81	Dec.	1954	—	6/860.98	.708	—	—	—	SCS
	do	do	do	—	—	July	1961	6.63	6/854.63	.703	—	6/.53	—	
	do	do	do	—	—	Dec.	54	—	7/221.96	.183	—	—	—	
	do	do	do	—	—	July	1961	6.63	7/215.77	.177	—	7/.51	—	
44-12	Six Mile Creek No. 23	Trib. of Hurricane Creek	Peter Pender, Ark.	4.16	3.91	July	1955	—	6/989.25	.372	—	—	—	SCS
	do	do	do	—	—	July	1961	6.00	6/983.27	.369	—	6/.26	—	
	do	do	do	—	—	July	1955	—	7/75.92	.029	—	—	—	
	do	do	do	—	—	July	1961	6.00	7/70.64	.027	—	7/.23	—	

1/ Conservation pool capacity. Reservoir has greater capacity at spillway crest elevation.
2/ Includes 0.03 ac.-ft. above crest deposits.
3/ 1937-1955=39,097 sq. mi.; 1956-1961=34,692 sq. mi.
4/ Suspended - load inflow was 608 ac.-ft.; suspended - load outflow was 200 ac.-ft. during period. Deposits too small to measure by range survey.
5/ Sediment inflow volume was computed to be 2,350 ac.-ft.; much of this probably settled out over a large area in deposits too thin to be measured accurately by echo sounders.
6/ Both sediment and flood pools.
7/ Sediment pool only.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	ARKANSAS RIVER BASIN (VAN BUREN TO LITTLE ROCK) WHITE RIVER BASIN (Continued)												
44-13	Dardanelle Reservoir	Arkansas River	Dardanelle, Ark.	1/153,703	11,333	Oct. 1964	—	460,300	2/.0532	—	—	—	CE
	do	do	do	—	—	Oct. 1965	1.00	452,600	2/.0532	*80	0.626	1,090	
	do	do	do	—	—	Apr. 1968	2.50	443,500	2/.0540	80	.321	560	
44-14	Six Mile Creek Site No. 6	Six Mile Creek	Chismville, Ark.	4.14	4.07	Oct. 1954	—	1,304.03	.446	—	—	—	SCS
	do	do	do	—	—	May 1964	9.58	1,275.62	.436	68.8	.73	1,093	
	do	do	do	—	—	Oct. 1970	6.42	1,253.26	.429	76.1	.86	1,425	
	ARKANSAS RIVER BASIN (TULSA TO VAN BUREN) Grand, Verdigris, and Lower Canadian River Basins												
45-1	Lake Wedington	Trib. of Illinois River	Fayetteville, Ark.	4.06	3.92	July 1937	—	1,260	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1947	10.1	1,249	—	—	.278	—	
45-2	Wilson	Wilson Creek	do	2.35	2.30	Oct. 1930	—	522	—	—	—	—	SCS
	do	do	do	—	—	June 1940	9.75	517	—	—	.23	—	
45-3	Lake Sapulpa	Rucher Creek	Sapulpa, Okla.	8.72	8.57	— 1913	—	1,094	—	—	—	—	SCS
	do	do	do	—	—	Dec. 1935	22.5	911	—	—	.949	—	
	do	do	do	—	—	Dec. 1946	11.0	842	—	—	.732	—	
45-4b	Brown Lake	Peaceable Creek	McAlester, Okla.	20.9	19.9	May 1943	—	4,995	.640	—	—	—	SCS
	do	do	do	—	—	July 1952	9.2	4,660	.597	54.2	1.83	2,160	
	do	do	do	—	—	Apr. 1963	10.75	4,525	.580	—	.63	743	
45-5	Lake McAlester	Bull Creek	do	30.7	28.2	— 1919	—	18,397	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1941	22	17,509	—	—	1.43	—	
45-6	Lake Okmulgee	Salt Creek	Okmulgee, Okla.	40.1	39.2	— 1928	—	10,355	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1950	22	9,896	—	—	.532	—	
45-7a	Shawnee Lake	Deer Creek	Shawnee, Okla.	21.2	18.9	Aug. 1935 3/	—	3/22,600	—	—	—	—	SCS
								24,468	—	—	—	—	
	do	do	do	—	—	Dec. 1947 4/	12.3	5/23,816	—	94.72	2.8	5,776	
								23,429	—	—	—	—	
	do	do	do	—	—	Mar. 1957	9.2	5/22,327	—	94.72	2.7	5,339	
45-8	Taft Lake	Br. of Pecan Creek	Taft, Okla.	2.3	2.2	— 1937	—	580	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1947	10	574	—	—	.29	—	
45-9	Hiwassee Lake	Trib. of Deep Fk. Creek	Arcadia, Okla.	4.58	4.29	— 1936	—	2,341	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1950	14	2,158	—	—	3.05	—	
45-10	Lake Carleton	Fourche Maline Creek	Wilburton, Okla.	19.8	19.7	— 1933	—	6/570	—	—	—	—	SCS
	do	do	do	—	—	July 1947	14	521	—	—	.21	—	
45-11	Holdenville City Lake	Beemore Creek	Holdenville, Okla.	8.95	8.30	June 1931	—	9,844	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1950	18.8	9,030	—	—	5.22	—	
45-12	Pretty Water Lake	Pretty Water Creek	Sapulpa, Okla.	2.43	2.40	Mar. 1936	—	344	—	—	—	—	SCS
	do	do	do	—	—	Dec. 1946	10.75	322	—	—	.85	—	
45-13	Greenleaf Lake	Big Greenleaf Creek	Muskogee, Okla.	81.25	79.84	Mar. 1937	—	13,005	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1941	4.7	12,828	—	—	.47	—	
45-15	Kirk Lake	Unnamed	Iola, Kans.	2.41	2.36	— 1897	—	111	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1939	42	69	—	68.10	.43	450	
45-16	Lowell	Sprg. R. & Shoal Creek	Baxter Springs, Kans.	2,210.0	2,208.6	Mar. 1905	—	10,404	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1939	34.4	7,580	—	*60	.06	52.3	
45-17	Neosho County State Lake (Lake McKinley).	Small Trib. of Neosho River	Parsons, Kans.	3.38	3.24	July 1927	—	680	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1939	12.1	651	—	*60	.76	967	
45-18	Lake Claremore	Dog Creek	Claremore, Okla.	56.44	55.70	May 1931	—	4,258	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1939	8.4	3,909	—	51.17	.749	835	
45-19	Lake Spavinaw	Spavinaw Creek	Spavinaw, Okla.	400.0	397.2	Apr. 1924	—	31,686	—	—	—	—	SCS
	do	do	do	—	—	July 1935	11	30,509	—	—	.269	—	
45-20	Kennamer Lake	Trib. of Pryors Creek	Chelsea, Okla.	.28	.27	— 1923	—	28	—	—	—	—	SCS
	do	do	do	—	—	— 1939	16	26.5	—	—	.35	—	
45-21	State Fish Hatchery Lake	Happy Creek	Claremore, Okla.	1.21	1.20	— 1934	—	34.0	—	—	—	—	SCS
	do	do	do	—	—	— 1939	5	32.9	—	—	.18	—	
45-22	Lake Scarbow	Trib. of Pryor Creek	Pryor, Okla.	3.07	3.04	— 1931	—	123	—	—	—	—	SCS
	do	do	do	—	—	— 1939	8	111.9	—	—	.46	—	
45-23	Wewoka Lake	Coon Cr. or Spring Cr.	Wewoka, Okla.	16.27	15.72	July 1925	—	7/4,961	1.028	—	—	—	SCS
	do	do	do	—	—	Apr. 1945	19.6	4,489	.930	—	1.51	—	
	do	do	do	—	—	Feb. 1954	8.0	4,357	.903	—	8/1.05	—	
45-24	Wetumka City Lake	Salt Creek	Wetumka, Okla.	4.15	3.88	Jan. 1931	—	2,076	1.341	—	—	—	SCS
	do	do	do	—	—	Feb. 1954	23.2	1,898	1.226	—	1.98	—	
45-25	Adair	N. Caney River	Sedan, Kans.	.33	.33	Mar. 1953	—	20.9	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	7.5	20.2	—	55	.28	335	
45-26	Bevoy	Big Caney River	Cedar Vale, Kans.	.16	.16	Jan. 1938	—	22.8	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	22.7	21.2	—	60	.44	574	

45-27	Buffalo	Bee Creek	Havana, Kans.	.26	.25	— 1934	—	51.7	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	26	48.5	—	50	.45	490	
45-28a	Foster	W. Caney River	Sedan, Kans.	2.25	2.25	Jan. 1951	—	484	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1960	9.5	477.8	—	55	.29	347	
45-29	House	Caney River	Hewins, Kans.	.25	.25	Sept. 1936	—	10.66	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	24	9.26	—	60	.23	300	
45-30	Herbert Miles Pond	Unnamed	Lebo, Kans.	.194	.192	Jan. 1939	—	10.59	—	—	—	—	SCS
	do	do	do	—	—	July 1957	18.5	8.56	—	*60	9/.60	9/810.2	
45-31	Kahola	Kahola Creek	Dunlap, Kans.	15.9	15.3	Dec. 1936	—	6,491	*1.591	—	—	—	ARS
	do	do	do	—	—	Apr. 1954	18.3	5,935	*1.455	51.6	1.99	2,236	
45-32	Wille	Big Caney River	Sedan, Kans.	.2	.2	— 1920	—	23.9	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	40	21.6	—	70	.28	427	
45-33	Payer Pond	Unnamed	Burlington, Kans.	.345	.345	Jan. 1938	—	54.97	—	—	—	—	SCS
	do	do	do	—	—	July 1957	19.5	44.12	—	57	1.61	1,998.0	
45-34	Staats	Middle Caney River	Cedarvale, Kans.	.49	.49	Jan. 1943	—	81.46	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	17.7	77.96	—	60	.41	536	
45-35	Hulah	Caney River	Hulah, Okla.	732	712	Feb. 1950	—	295,130	1.109	—	—	—	CE
	do	do	do	—	—	June 1958	8.4	292,565	1.099	44.2	.429	413	
45-36a	Double Creek Site No. 5	do	Ramona, Okla.	2.39	2.36	Feb. 1955	—	747.36	.83	—	—	—	SCS
	do	do	do	—	—	Apr. 1964	9.2	734.29	.81	54.3	.60	710	
	do	do	do	—	—	Sept. 1969	5.5	730.53	.81	54.3	.29	343	
45-37	Waldron Lake	Square Rock Creek	Waldron, Ark.	7.65	7.58	Mar. 1943	—	361.44	.059	—	—	—	SCS
	do	do	do	—	—	Oct. 1961	18.58	325.78	.053	—	.25	—	
45-38	Howard City Lake	Game Creek	Howard, Kans.	10.16	10.06	Sept. 1936	—	771.0	.316	—	—	—	SCS
	do	do	do	—	—	Sept. 1965	28.9	604.7	.268	*60	.57	745	
45-39	Heyburn Reservoir	Polecat Creek	Heyburn, Okla.	123	117	Mar. 1950	—	59,650	1.447	—	—	—	CE
	do	do	do	—	—	Dec. 1959	9.8	57,270	1.389	77.23	2.08	3,499	
45-40	Toronto Lake	Verdigris	Toronto, Kans.	730	714	Mar. 1960	—	195,300	.599	—	—	—	CE
	do	do	do	—	—	May 1966	6.21	192,060	.550	50.4	.731	802	
45-41	Eufaula Lake	Canadian	Whitefield, Okla.	47,522	13,693	Feb. 1964	—	3,848,000	.89	—	—	—	CE
	do	do	do	—	—	June 1969	5.33	3,798,400	.88	62.2	.68	921	
45-42	Hatch	Trib. Neosho River	Burlington, Kans.	.19	.18	Oct. 1939	—	4.74	.07	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	28	3.54	.05	*60	.24	314	
45-43	Mound Valley Experimental Sta.	Trib. of Pumpkin Creek	Mound Valley, Kans.	.42	.42	June 1954	—	6.90	.032	—	—	—	SCS
	do	do	do	—	—	June 1968	14	4.77	.022	*60	.36	470	
45-44	Cranor	Trib. Verdigris River	Edna, Kans.	.22	.22	Nov. 1953	—	5.08	.044	—	—	—	SCS
	do	do	do	—	—	June 1968	14.6	3.92	.034	*60	.32	418	
45-45	Scott	Trib. Neosho	Parsons, Kans.	.23	.23	Dec. 1956	—	12.0	.10	—	—	—	SCS
	do	do	do	—	—	June 1968	11.8	11.1	.093	*60	.33	457	
45-46	Fletcher	Big Creek	Gridley, Kans.	.20	.19	— 1934	—	24.41	.33	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	33	20.1	.27	*60	.68	888	
45-47	Isch Pond	do	do	.38	.37	— 1927	—	15.37	.110	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	40	8.72	.062	*60	.46	601	
45-48	Hess Pond	Trib. Duck Creek	Elk City, Kans.	1.75	1.73	— 1933	—	53.04	.080	—	—	—	SCS
	do	do	do	—	—	July 1967	34	29.69	.045	*60	.40	522	
45-49	Olenhouse	do	La Fontaine, Kans.	.13	.13	July 1937	—	3.8	.080	—	—	—	SCS
	do	do	do	—	—	July 1967	30	3.0	.062	*60	.23	300	
45-50	Sierman	do	do	.23	.23	June 1937	—	5.3	.062	—	—	—	SCS
	do	do	do	—	—	July 1967	30	4.5	.052	*60	.13	170	
45-51	Hubert	do	Longton, Kans.	.41	.40	Oct. 1948	—	16.38	.11	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	19	15.0	.098	*60	.18	235	
45-52	Meritt Pond	Big Creek	Burlington, Kans.	.25	.25	— 1939	—	8.09	.09	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	28	4.17	.065	*60	.56	731	
45-53	Big Wewoka Site No. 36	Big Wewoka	Holdenville, Okla.	2.26	2.20	June 1960	—	690.3	.95	—	—	—	SCS
	do	do	do	—	—	Aug. 1969	9.1	679.0	.94	62	.56	762	
45-54	Cane Creek Site No. 11	Cane Creek	Okmulgee, Okla.	8.96	8.89	Nov. 1965	—	2,983.6	.96	—	—	—	SCS
	do	do	do	—	—	Sept. 1969	3.85	2,954.7	.95	55	.85	1,018	
45-55	Big Wewoka Site No. 17	Big Wewoka	Wewoka, Okla.	2.16	2.11	Mar. 1963	—	691.3	1.36	—	—	—	SCS
	do	do	do	—	—	Sept. 1968	5.53	680.7	1.34	60	.91	1,189	

ARKANSAS RIVER BASIN (GARDEN CITY TO TULSA)

Middle Canadian, Lower Cimarron, and Salt Fork River Basins

46-1b	Fort Supply Lake	Wolf Creek	Fort Supply, Okla.	1,735	1,485	Jan. 1943	—	107,340	1.27	—	—	—	CE
	do	do	do	—	—	June 1949	6.42	106,150	1.26	57.8	.125	197	
	do	do	do	—	—	June 1958	9.0	101,750	1.21	67.0	.329	498	
	do	do	do	—	—	Dec. 1969	11.50	100,720	1.66	65.3	.061	74	

1/ 22,241 sq. mi. is probably noncontributing.
2/ Based on inflow from net sediment contributing area.
3/ Original topographic survey.
4/ From "A" reconnaissance investigation, Shawnee Lake, by Victor H. Jones, Geologist, SCS.
5/ Present ac.-ft. as shown by the two surveys.
6/ Lake drained and dam raised 1937. Original capacity at 1938 crest.
7/ Dam raised 11 feet Mar. 1946; all values based on present elevation.
8/ Dam broke Apr. 1945; rebuilt Mar. 1946; this period not included.
9/ Includes 0.03 ac.-ft. above crest deposits.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	ARKANSAS RIVER BASIN (GARDEN CITY TO TULSA) Middle Canadian, Lower Cimarron, and Salt Fork River Basins (Continued)												
46-2a	Great Salt Plains	Salt Fk. of Arkansas River	Jet, Okla.	3,200	3,156	June 1941	—	308,000	1.067	—	—	—	CE
	do	do	do	—	—	Dec. 1949	8.5	292,000	1.011	48.6	0.586	620	
	do	do	do	—	—	Apr. 1961	11.4	280,200	.971	58.9	.336	529	
46-3	Boomer Lake	Boomer Creek	Stillwater, Okla.	9.13	8.67	Mar. 1925	—	2,812	—	—	—	—	SCS
	do	do	do	—	—	June 1935	10.25	2,641	—	*60	1.93	2,522	
46-4	Bennington's Lake	Chikaskia River	Rago, Kans.	1.42	1.40	Aug. 1929	—	75	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1940	11.2	33	—	69.47	2.68	4,055	
46-5	Meade County State Lake (Lake Larrabee).	Stump Arroya	Meade, Kans.	18.00	17.84	June 1928	—	891	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1937	8.8	819	—	*60	.459	600	
46-6	Lake Medicine	Medicine Lodge Creek	Medicine Lodge, Kans.	1.89	1.84	Aug. 1929	—	365	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1940	11.2	295	—	98.52	3.40	7,296	
46-7	Santa Fe	Indianola Creek	Augusta, Kans.	37.93	37.55	Oct. 1928	—	1,741	—	—	—	—	SCS
	do	do	do	—	—	May 1937	8.6	1,595	—	58.1	.45	569	
46-8	Guthrie	Trib. of Cottonwood Creek	Guthrie, Okla.	13.30	12.95	Oct. 1920	—	3,064	—	—	—	—	SCS
	do	do	do	—	—	May 1935	14.5	2,608	—	*60	2.42	3,162	
46-9	Gelmer's Stock Pond	Bois d'Arc Creek	Blackwell, Okla.	.31	.31	Oct. 1939	—	3.74	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1940	1.0	3.43	—	*65	1.0	1,416	
46-10	Harris Stock Pond	do	do	.22	.21	Apr. 1938	—	12.63	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1940	2.5	12.37	—	*65	.495	701	
46-11	Lake Eldorado	Satchel Creek	Eldorado, Kans.	35.1	34.3	— 1928	—	3,213	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1937	9	3,082	—	66	.426	612	
46-12a	Lake Fryer	Wolf Creek	Perryton, Tex.	108	108	— 1939	—	844	.372	—	—	—	SCS
	do	do	do	—	—	May 1947	7.4	717	.316	—	.16	—	
46-13b	Canton Lake	North Canadian River	Canton, Okla.	12,483	1/6,081	July 1947	—	401,500	2.15	—	—	—	CE
	do	do	do	—	—	May 1953	5.83	390,800	2.10	70.9	.302	4,664	
	do	do	do	—	—	Oct. 1959	6.42	385,900	2.07	56.2	.125	65.3	
	do	do	do	—	—	Sept. 1966	6.92	383,300	2.06	56.1	.063	76.4	
46-14	Guthrie Municipal Reservoir No. 2.	Cottonwood Creek	Guthrie, Okla.	11.63	11.29	May 1949	—	3,192.68	1.391	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	11.40	2,945.06	1.283	95.66	1.92	4,000.27	
46-15a	Lake Carl Blackwell	Stillwater Creek	Stillwater, Okla.	75.35	70.53	Mar. 1938	—	58,326	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1958	20.50	54,556	—	*60	2.61	3,410.75	
46-16	Lies Pond	Unnamed	Andale, Kans.	3.36	3.36	June 1942	—	20.44	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1956	14	9.62	—	96.09	2/.28	3/578.68	
46-17	Longton	do	Cimarron, Kans.	.55	.54	July 1935	—	3/51.10	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	20	50.28	—	85.7	.07	134	
46-18	Hughes No. 1	do	Ingalls, Kans.	.64	.63	— 1942	—	3/8.50	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	13	5.44	—	72.07	.32	502	
46-19	Perry City Lake	Cow Creek	Perry, Okla.	16.67	16.64	June 1937	—	4,371	1.311	—	—	—	SCS
	do	do	do	—	—	May 1955	17.9	3,986	1.196	83.5	1.33	2,419	
46-20	Pottesinger Pond	Unnamed	Andale, Kans.	.9	.9	Aug. 1949	—	16.87	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1956	7	8.97	—	103.4	4/1.0	4/2,252	
46-21	O. F. Scott Ponds	Trib. of So. Canadian R.	Union City, Okla.	1.80	1.79	May 1941	—	26.3	.085	—	—	—	SCS
	do	do	do	—	—	May 1955	14	20.7	.067	65.4	.22	313	
46-22	Tom Hill Pond	Trib. of Bridge Creek	Tuttle, Okla.	.530	.526	July 1943	—	13.38	.147	—	—	—	SCS
	do	do	do	—	—	May 1955	11.8	6.43	.071	—	1.12	—	
46-23	Michlaes	Trib. Slough Creek	Haven, Kans.	2.29	2.27	May 1932	—	46.14	.15	—	—	—	SCS
	do	do	do	—	—	May 1967	35	5/13.6	.04	70	.22	335	
46-24	Thaver	Trib. Slate Creek	Wellington, Kans.	.14	.14	— 1958	—	4.09	.16	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	9	3.38	.13	*60	.57	745	
46-25	Koniecrie	Trib. Sand Creek	Newton, Kans.	.24	.24	Oct. 1948	—	9.64	.219	—	—	—	SCS
	do	do	do	—	—	Sept. 1968	19.92	6.95	.158	*60	.58	758	
46-26	Adams	Trib. Bluff Creek	Anthony, Kans.	.24	.23	Sept. 1934	—	13.50	.56	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	33.92	5.76	.24	*60	1.00	1,307	
46-27	Smith - Case	Trib. Little Ark. River	Little River, Kans.	.56	.56	Dec. 19[illegible]	—	66.89	1.86	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	9.75	62.29	1.73	*60	.84	1,098	
46-28	Workman	Trib. Medicine Lodge River	Medicine Lodge, Kans.	.59	.59	June 1936	—	10.0	.18	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	32.17	1.79	.03	*60	.44	575	
46-29	Gant	do	do	.30	.30	Mar. 1955	—	25.26	.87	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	13.42	20.29	.70	*60	1.23	1,607	
46-30	Schupbach	do	Kiowa, Kans.	.34	.34	June 1956	—	26.73	.81	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	12.17	21.91	.66	*60	1.18	1,542	
46-31	Barrett	Wild Creek	Anthony, Kans.	.67	.67	Spring 1957	—	39.92	.59	—	—	—	SCS
	do	do	do	—	—	July 1968	11.25	32.24	.47	*60	1.01	1,320	
46-32	Miller	Beaver Creek	Walton, Kans.	1.20	1.20	Aug. 1959	—	6.08	.038	—	—	—	SCS
	do	do	do	—	—	July 1968	9	2.87	.013	*60	.30	392	

46-33	Roupp	Trib. Sand Creek	Hesston, Kans.	.49	.49	June 1950	—	5.47	.066	—	—	—	SCS
	do	do	do	—	—	Sept. 1963	18.12	3.33	.037	*60	.24	314	
46-34	Mease	Trib. Medicine Lodge River	Medicine Lodge, Kans.	1.73	1.71	Feb. 1961	—	108.3	.65	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	7.5	105.19	.63	*60	.24	314	
46-35	Berger Pond	Trib. Pawnee River	Jetmore, Kans.	3.0	3.0	Mar. 1952	—	18.55	.29	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	15.5	12.95	.20	*60	.12	156	
46-36	Paris	Trib. Wet Walnut Creek	Dighton, Kans.	3.6	2.2	Aug. 1940	—	41.69	.87	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	27	36.66	.76	*60	.09	117	
46-37	Siebert	Trib. Big Sandy	Meade, Kans.	.23	.23	Jan. 1952	—	8.0	1.6	—	—	—	SCS
	do	do	do	—	—	June 1966	14.5	7.15	1.5	80	.26	453	
46-38	Hoop	Trib. Crooked Creek	do	1.07	.90	May 1961	—	4.0	.19	—	—	—	SCS
	do	do	do	—	—	June 1966	5.2	3.76	.19	80	.06	104	
46-39	Harris	do	do	7.57	4.75	Oct. 1962	—	161.4	1.1	—	—	—	SCS
	do	do	do	—	—	June 1966	3.7	160.8	1.1	*70	.04	61	
46-40	Whitford	Trib. Hackberry Creek	Ashland, Kans.	1.98	1.97	May 1947	—	14.2	.22	—	—	—	SCS
	do	do	do	—	—	July 1966	19.2	8.2	.13	75.	.15	245	
46-41	Davis	Pawnee	Kalvesta, Kans.	2.40	2.37	Jan. 1951	—	104.82	3.28	—	—	—	SCS
	do	do	do	—	—	Sept. 1967	16.75	97.94	3.06	*60	.17	222	
46-42	Lippoldt	Trib. Pawnee River	Jetmore, Kans.	1.83	1.82	Dec. 1952	—	6/ 30.5	.78	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	14.75	27.74	.71	*60	.10	131	
46-43	Sebes Pond	do	do	1.20	1.20	July 1956	—	5.6	.22	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	11.13	4.34	.17	*60	.09	117	
46-44	Fry	Trib. Ark. River	Little River, Kans.	1.07	1.07	Aug. 1949	—	4.13	.06	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	19	1.37	.02	*60	.14	183	
46-45	Barber	do	Raymond, Kans.	.57	.57	June 1962	—	21.50	.60	—	—	—	SCS
	do	do	do	—	—	June 1968	6.2	17.97	.50	*70	1.0	1,525	
46-46	Coberly	Trib. Buffalo Creek	Dighton, Kans.	2.1	2.1	Aug. 1946	—	18.0	.65	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	21	12.93	.48	*60	.11	143	
46-47	Smith Pond	Trib. Pawnee River	Jetmore, Kans.	.30	.30	Dec. 1951	—	5.93	.93	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	15.75	3.56	.59	*60	.50	653	
46-48	Seltman	Trib. Walnut Creek	Rush Center, Kans.	1.63	1.61	Oct. 1958	—	26.07	.43	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	8.8	22.23	.37	*60	.27	352	
46-49	Rayl	Trib. Slate Creek	Wellington, Kans.	.56	.56	— 1949	—	5.44	.05	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	18	2.96	.03	*60	.25	326	
46-50	Lange	do	Conway Springs, Kans.	.31	.31	— 1956	—	8.11	.14	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	11	5.37	.09	*60	.81	1,058	
46-51	Brodie	Spring Creek	Ashland, Kans.	2.17	2.0	June 1951	—	31.2	.36	—	—	—	SCS
	do	do	do	—	—	July 1966	15.1	29.0	.33	*70	.07	107	
46-52	Glen	Trib. Little Sandy Creek	do	.95	.93	Nov. 1958	—	57.1	1.88	—	—	—	SCS
	do	do	do	—	—	July 1966	7.75	54.5	1.79	*60	.35	457	
46-53	Isaac	Trib. Big Sandy	Meade, Kans.	.82	.52	Jan. 1952	—	6.65	.38	—	—	—	SCS
	do	do	do	—	—	June 1966	14.5	4.8	.27	75	.25	408	
46-54	Fox	Trib. Bluff Creek	Ashland, Kans.	2.18	2.17	July 1954	—	10.0	.11	—	—	—	SCS
	do	do	do	—	—	July 1966	12	7.3	.08	*65	.11	156	

ARKANSAS RIVER BASIN (LAMAR TO GARDEN CITY)
Upper Cimarron and Upper Canadian River Basins

47-1b	Conchas Reservoir	Canadian and Conchas	Conchas Dam, N. Mex.	7,409	6,976	Jan. 1939	—	601,112	3.13	—	—	—	CE
	do	do	do	—	—	May 1940	1.4	599,712	3.12	75.7	—	—	
	do	do	do	—	—	June 1942	2.1	585,112	3.04	75.7	.996	1,643	
	do	do	do	—	—	Nov. 1942	.4	581,112	3.02	75.7	—	—	
	do	do	do	—	—	Oct. 1944	1.9	576,756	3.00	75.7	.328	541	
	do	do	do	—	—	Feb. 1949	4.3	566,163	2.95	*75.7	.353	581	
	do	do	do	—	—	Oct. 1963	14.7	550,799	2.87	*75.7	.150	247	
	do	do	do	—	—	Oct. 1970	6.92	528,951	2.75	75.7	.453	746	
47-2	Reservoir No. 2	(Offstream)	Maxwell, N. Mex.	—	—	— 1912	—	3,010	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	1,836	—	—	—	—	
47-3	Reservoir No. 7 and 8	do	do	—	—	— 1912	—	7/ 1,064	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	2,063	—	—	—	—	
47-4	Reservoir No. 11	do	do	—	—	— 1912	—	8/ 1,004	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	637	—	—	—	—	
47-5	Reservoir No. 12	do	do	—	—	— 1912	—	9/ 2,260	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	1,822	—	—	—	—	
47-6	Reservoir No. 13	do	do	—	—	— 1912	—	10/ 2,236	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	1,628	—	—	—	—	
47-7	Reservoir No. 14	do	do	—	—	— 1912	—	11/ 816	—	—	—	—	BR
	do	do	do	—	—	— 1946	34	680	—	—	—	—	
47-8	Bolee	Cimarron	Liberal, Kans.	.36	.36	Mar. 1962	—	9.16	1.9	—	—	—	SCS
	do	do	do	—	—	June 1966	4.25	8.98	1.9	*65	.12	170	

1/ Excludes 4,642 sq. mi. of watershed not contributed to runoff, 1,735 sq. mi. above Fort Supply Dam, and 25 sq. mi. surface area of Canton Reservoir.
2/ Includes 2.33 ac.-ft. above crest deposits.
3/ Water supply pool capacity. Reservoir has greater capacity at spillway crest elevation.
4/ Includes 0.39 ac.-ft. above crest deposits.
5/ Spillway eroded 2 ft.
6/ Capacity based on surface area x 1/3 deepest fill.
7/ During the period 1912-46, a total of 2,435-ac.-ft. capacity was added by reservoir enlargement.
8/ During the period 1912-46, a total of 126-ac.-ft. capacity was added by reservoir enlargement.
9/ During the period 1912-46, a total of 672-ac.-ft. capacity was added by reservoir enlargement.
10/ During the period 1912-46, a total of 490-ac.-ft. capacity was added by reservoir enlargement.
11/ During the period 1912-46, a total of 264-ac.-ft. capacity was added by reservoir enlargement.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
ARKANSAS RIVER BASIN (LAMAR TO GARDEN CITY) Upper Cimarron and Upper Canadian River Basins (Continued)													
47-9	Gregory	Trib. Ark. River	Syracuse, Kans.	6.5	6.5	Apr. 1951	—	62.2	1.79	—	—	—	SCS
	do	do	do	—	—	June 1967	16.5	50.83	1.50	70	0.11	167	
47-10	Lahey	Trib. Cimarron	Moscow, Kans.	2.78	2.75	Oct. 1960	—	135.6	4.6	—	—	—	SCS
	do	do	do	—	—	June 1966	5.7	133.8	4.5	*50	.11	130	
47-11	Hartshorn	Trib. Little Bear Creek	Syracuse, Kans.	1.90	1.89	Mar. 1950	—	14.6	.72	—	—	—	SCS
	do	do	do	—	—	June 1966	16.25	8.75	.43	*75	.19	310	
47-12	Christian	Trib. Cimarron	Ulysses, Kans.	1.06	1.06	June 1961	—	4.5	.40	—	—	—	SCS
	do	do	do	—	—	June 1966	5	3.75	.33	*75	.14	229	
47-13	Downing	do	Moscow, Kans.	.47	.46	Aug. 1961	—	31.8	6.4	—	—	—	SCS
	do	do	do	—	—	June 1966	4.8	31.2	6.2	65	.28	396	
47-14	Amerine	Trib. Little Bear Creek	Syracuse, Kans.	3.42	3.40	Mar. 1953	—	128	3.5	—	—	—	SCS
	do	do	do	—	—	June 1966	13.3	119	3.3	*75	.20	327	
47-15	Roy Kurz	Shirley	do	8.91	8.91	Apr. 1951	—	92.7	1.97	—	—	—	SCS
	do	do	do	—	—	June 1967	16.5	78.2	1.65	*70	.10	152	
RIO GRANDE BASIN (ABOVE ESPANOLA) AND ARKANSAS RIVER BASIN													
48-14	John Martin Reservoir (formerly Caddoa Res. Proj.).	Arkansas River	Hasty, Colo.	1/18,915	18,102	Apr. 1942	—	701,775	2.47	—	—	—	CE
	do	do	do	—	—	July 1942	0.3	690,345	2.43	*75.7	—	—	
	do	do	do	—	—	Dec. 1943	1.4	688,590	2.43	*75.7	.075	126	
	do	do	do	—	—	Sept. 1944	0.7	683,257	2.41	*75.7	.443	730	
	do	do	do	—	—	May 1948	3.7	675,097	2.38	*75.7	.129	213	
	do	do	do	—	—	Oct. 1951	3.4	662,870	2.34	*75.7	.210	346	
	do	do	do	—	—	Aug. 1957	5.7	645,512	2.28	*75.7	.178	293	
	do	do	do	—	—	Mar. 1962	4.6	642,390	2.26	*75.7	.0398	65.6	
	do	do	do	—	—	Sept. 1966	4.5	631,121	2.22	*75.7	.147	242	
	do	do	do	—	—	Aug. 1968	1.9	618,668	2.18	*75.7	.362	597	
48-2	Brown Reservoir No. 1	Van Bremer Arroyo	Trinidad, Colo.	74.6	74.4	— 1900	—	758	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1939	39	82	—	89.07	.233	452	
48-3	Muddy Creek	Muddy Creek, Johnny Creek	Caddoa, Colo.	154.2	152.4	Fall 1919	—	16,918	—	—	—	—	SCS
	do	do	do	—	—	Dec. 1939	20	15,287	—	75.25	.535	877	
48-4	Horse Creek 2/	Horse Creek	Ordway, Colo.	52.01	47.44	Nov. 1900	—	36,203	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1940	39.4	30,738	—	68.36	3/.241	4/1,515	
48-5	Teller	Turkey Creek	Pueblo, Colo.	78.8	78.5	Mar. 1911	—	6,005	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1940	28.9	2,463	—	75.6	.680	1,117	
48-6	Cucharas	Cucharas River	Walsenburg, Colo.	608	608	— 1912	—	38,274	—	—	—	—	BR
	do	do	do	—	—	— 1937	25	25,020	—	—	.87	—	
	do	do	do	—	—	— 1939	2	23,060	—	—	1.63	—	
48-7	S-1 Big Sandy Creek Watershed	Big Sandy Creek	Peyton, Colo.	5.4	5.3	May 1962	—	326	—	—	—	—	SCS
	do	do	do	—	—	July 1965	3	302	—	*80	1.5	2,613	
48-8	Abiquiu Reservoir	Rio Chama	Abiquiu, N. Mex.	2,146	2,127	Apr. 1963	—	579,039	1.80	—	—	—	CE
	do	do	do	—	—	Oct. 1967	4.58	572,695	1.78	*75.7	.65	1,072	
48-9	Hardesty Reservoir	Hungerford Hollow	Fowler, Colo.	13.48	13.36	— 1908	—	563	*3.9	—	—	—	SCS
	do	do	do	—	—	Mar. 1968	60	527	*3.7	—	5/.065	—	
RED RIVER BASIN (DENISON TO GRAND ECORE) Little and Sulphur River Basins													
49-1a	Lake Crook	Pine Creek	Paris, Tex.	51.6	49.6	Feb. 1923	—	11,487	.418	—	—	—	SCS
	do	do	do	—	—	Mar. 1936	13.1	10,755	.391	—	1.23	—	
	do	do	do	—	—	July 1956	19.7	9,964	.362	36.4	.81	642	
49-2a	Lake Gibbons	Trib. of Pine Creek	do	1.46	1.26	— 1900	—	6/1,394	1.792	—	—	—	SCS
	do	do	do	—	—	Mar. 1936	36	1,326	1.702	—	1.54	—	
	do	do	do	—	—	July 1956	20.3	1,285	1.652	31.5	1.52	1,043	
49-3	Nashville	Mine Creek	Nashville, Ark.	10.4	10.3	Mar. 1951	—	181	—	—	—	—	SCS
	do	do	do	—	—	July 1961	10.3	128	—	—	.50	—	
49-4	Jenkins Pond	Trib. of Lewis Creek	Mansfield, La.	.35	.32	Sept. 1925	—	157	.562	—	—	—	SCS
	do	do	do	—	—	Sept. 1954	29	150	.536	68.6	.78	1,165	
49-5	Gordon Country Club Lake	Ands Creek	Paris, Tex.	1.41	1.30	— 1898	—	558	.742	—	—	—	SCS
	do	do	do	—	—	June 1959	61.0	430	.572	33.14	1.62	1,169	
49-6	Bayou Bodcau	Bayou Bodcau River	Cotton Valley, La.	683	613	Nov. 1949	—	967,900	1.516	—	—	—	CE
	do	do	do	—	—	May 1961	11.5	967,900	1.516	—	—	—	

49-7a	Lake Texarkana	Sulphur River	Texarkana, Tex.	3,400	3,213	Sept.	1954	—	2,654,300	.13	—	—	—	CE
	do	do	do	—	—	Aug.	1958	3.92	2,654,300	.13	—	—	—	
	do	do	do	—	—	July	1970	12	2,654,300	.13	—	—	—	
49-8	Wallace Lake	Cypress Bayou	Shreveport, La.	266	251	Dec.	1946	—	96,100	.405	—	—	—	CE
	do	do	do	—	—	Oct.	1951	4.8	96,100	.405	—	—	—	
	do	do	do	—	—	Apr.	1961	9.5	96,100	.405	—	—	—	
49-9	Century Lake	Sulphur River	Sulphur Springs, Tex.	52.50	51.46	—	1953	—	3,495.2	.125	—	—	—	SCS
	do	do	do	—	—	Sept.	1962	9	2,787.9	.100	*85	1.53	2,832	
RED RIVER BASIN (ABOVE DENISON)														
50-1	Ardmore Club Lake	Caddo Creek	Ardmore, Okla.	4.15	3.91	Dec.	1922	—	1,797	—	—	—	—	SCS
	do	do	do	—	—	June	1938	15.5	1,644	—	40.7	2.52	2,234	
50-2	Byars Club Lake	Unnamed Stream	Byars, Okla.	2.66	2.55	—	1904	—	507	—	—	—	—	SCS
	do	do	do	—	—	—	1950	46	371	—	—	1.16	—	
50-3	Carter Lake	Big Glasses Creek	Madill, Okla.	1.81	1.70	—	1936	—	865	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1949	13	837	—	—	1.26	—	
50-4	J. J. Harrison Lake	Trib. of Washita River	Lindsay, Okla.	.88	.81	Feb.	1932	—	349	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1950	18	282	—	—	4.59	—	
50-5	C. W. Lester Farm Pond No. 1	Trib. of Broken Leg Creek	Cheyenne, Okla.	2.04	2.03	—	1945	—	42.4	—	—	—	—	SCS
	do	do	do	—	—	June	1949	4	22.8	—	—	2.41	—	
50-6	C. W. Lester Farm Pond No. 2	do	do	.64	.63	June	1944	—	16.3	—	—	—	—	SCS
	do	do	do	—	—	June	1949	5.0	13.1	—	—	1.02	—	
50-7	Santa Rosa Lake	Beaver Creek	Vernon, Tex.	336	334	Oct.	1929	—	15,755	—	—	—	—	SCS
	do	do	do	—	—	Jan.	1948	18.2	11,568	—	—	.689	—	
50-8	Lake Duncan	Fitzpatrick Creek	Duncan, Okla.	11.0	10.4	Oct.	1937	—	6,291	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1950	12.8	5,783	—	63.4	3.82	5,275	
50-9	Lake Clinton	Turkey Creek	Canute, Okla.	23.6	23.1	Dec.	1930	—	4,415	—	—	—	—	SCS
	do	do	do	—	—	June	1938	7.4	3,981	—	63.36	2.54	3,505	
	do	do	do	—	—	Nov.	1950	12.4	3,343	—	65.9	2.23	3,201	
50-10	Bellevue	Clay Creek	Bellevue, Tex.	*1.5	1.44	—	1888	—	131	—	—	—	—	SCS
	do	do	do	—	—	May	1938	50	85	—	—	.64	—	
50-11c	Altus Reservoir	North Fork Red River	Altus, Okla.	2,515	2,104	Dec.	1940 7/	—	192,842	—	—	—	—	BR
	do	do	do	—	—	June	1948	7.5	185,035	—	52.3	.495	564	
	do	do	do	—	—	July	1953	5.1	178,610	1.74	66.9	.599	1,104	
	do	do	do	—	—	Apr.	1967	13.8	168,117	1.61	70.2	.361	588	
50-12b	Lake Texoma (Denison Dam)	Red River	Denison, Tex.	39,719	28,925	July	1942	—	5,859,000	—	—	—	—	CE
	do	do	do	—	—	Oct.	1948	6.2	5,718,000	—	52.1	.785	891	
	do	do	do	—	—	June	1954	5.7	5,553,000	—	57.9	1.00	1,261	
	do	do	do	—	—	Mar.	1962	7.8	5,392,900	—	62.5	.709	965	
50-13	Barbour Pond	Trib. of Little Washita R.	Chickasha, Okla.	.68	.67	Sept.	1935	—	59.9	.512	—	—	—	SCS
	do	do	do	—	—	May	1955	19.7	41.8	.357	*75	1.37	2,238	
50-14a	Cavalry Creek Site No. 1	Washita	Cordell, Okla.	2.19	2.15	July	1948	—	505.4	3.05	—	—	—	SCS
	do	do	do	—	—	Sept.	1959	11.15	476.6	2.87	74.5	1.20	1,946	
	do	do	do	—	—	Aug.	1964	4.89	471.8	2.84	74.5	.46	746	
	do	do	do	—	—	June	1969	4.85	458.8	2.77	*74	1.25	1,993	
50-15a	Chigley Sandy Site No. 5	Chigley Sandy	Wynnewood, Okla.	.81	.79	June	1955	—	263.67	1.410	—	—	—	SCS
	do	do	do	—	—	Aug.	1959	4.12	258.74	1.384	60.3	1.52	1,996	
	do	do	do	—	—	Oct.	1963	4.15	248.20	1.327	60.3	3.22	4,229	
50-16	Coit Pond No. 1	Unnamed	Clinton, Okla.	.39	.38	Mar.	1947	—	25.69	.706	—	—	—	SCS
	do	do	do	—	—	July	1957	10.28	21.53	.591	61.49	1.07	1,433	
50-17	Dean Pond No. 1	Trib. of Nine Mile Creek	Cheyenne, Okla.	.0359	.0354	Spring	1944	—	1.078	.469	—	—	—	SCS
	do	do	do	—	—	Mar.	1955	11	.807	.351	91	.69	1,368	
50-18	Dean Pond No. 2	do	do	.164	.161	Spring	1941	—	15.8	1.505	—	—	—	SCS
	do	do	do	—	—	Mar.	1955	14	13.4	1.276	88	1.06	2,032	
50-19	George Pond	Unnamed	Canadian, Tex.	.535	.535	June	1952	—	15.197	.407	—	—	—	SCS
	do	do	do	—	—	Apr.	1958	5.796	13.463	.361	70.95	.559	863.82	
50-20	Hall Pond No. 1	do	Leedey, Okla.	.20	.20	May	1939	—	17.59	.239	—	—	—	SCS
	do	do	do	—	—	Aug.	1957	18.25	13.47	.183	*70.2	1.15	1,758.30	
50-21	Harrison No. 1	do	Canadian, Tex.	.237	.237	May	1952	—	22.163	.594	—	—	—	SCS
	do	do	do	—	—	Apr.	1958	5.93	21.706	.581	79.68	.325	564.01	
50-22	Harrison No. 2	do	do	.292	.292	Sept.	1951	—	15.655	.419	—	—	—	SCS
	do	do	do	—	—	Apr.	1958	6.59	14.242	.382	68.53	.733	1,094.06	
50-23	Lake Kemp	Wichita River	Seymour, Tex.	2,099	2,067	Oct.	1922	—	560,000	2.493	—	—	—	SCS
	do	do	do	—	—	Sept.	1958	36	461,757	2.056	—	1.32	—	
50-24a	Mill Creek No. 17	Washita	Mill Creek, Okla.	1.61	1.58	Dec.	1948	—	498.45	1.06	—	—	—	SCS
	do	do	do	—	—	July	1959	10.63	492.13	1.04	70	.37	564	
	do	do	do	—	—	Aug.	1966	7.06	487.11	1.03	*75	.45	816	
50-25	Muncrief Farm Pond	Trib. of Sandy Creek	Wynnewood, Okla.	.031	.029	Aug.	1935	—	8.710	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1957	22.22	7.968	—	*60	1.15	1,502.82	

1/ Drainage area adjusted to conform with U.S.G.S. published drainage area.

2/ Off channel reservoir.

3/ Excludes water and sediment diverted from Arkansas River and Horse Creek.

4/ Per 100 ac.-ft. of water diverted from Ark. River and Horse Cr. Total of 564,918 ac.-ft. diverted to reservoir between 1910 and 1939.

5/ Little deposition due to dam washout, 1930-47. True sediment accumulation rate for 43-yr period was about 0.063 ac.-ft./mi^2-yr.

6/ Spillway crest was lowered 3 ft. in 1932; capacities are based on present elevation.

7/ Date of original survey for new dam over deposits placed behind old dam.

* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
RED RIVER BASIN (ABOVE DENISON) (Continued)													
50-26a	Cobb Creek No. 3	Washita	Weathertore, Okla.	8.28	8.18	Jan. 1957	—	2,401.1	2.72	—	—	—	SCS
	do	do	do	—	—	Aug. 1960	3.58	2,303.3	2.61	90	3.36	6,547	
	do	do	do	—	—	Oct. 1964	4.14	2,277.3	2.58	90	.77	1,509	
	do	do	do	—	—	Aug. 1970	5.81	2,218.1	2.51	*91	1.24	2,563	
50-27b	Sandstone Site No. 1	do	Hammon, Okla.	5.33	5.22	May 1951	—	1,591.29	4.67	—	—	—	SCS
	do	do	do	—	—	Apr. 1956	4.96	1,453.69	4.26	61.49	5.31	7,111	
	do	do	do	—	—	May 1960	4.06	1,380.47	4.05	83.11	3.46	6,263	
	do	do	do	—	—	Aug. 1965	5.02	1,344.75	3.94	83.11	1.36	2,462	
	do	do	do	—	—	July 1970	4.92	1,338.82	3.93	*80	.23	360	
50-28b	Sandstone Site No. 3	do	Elk City, Okla.	.62	.61	Apr. 1951	—	157.68	4.38	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	5.47	148.40	4.12	70.20	2.79	4,266	
	do	do	do	—	—	Oct. 1961	5.00	139.98	3.89	77.87	2.75	4,672	
	do	do	do	—	—	July 1966	4.80	125.60	3.49	*77	4.92	8,184	
50-29a	Sandstone Site No. 5	do	do	3.89	3.84	Mar. 1951	—	1,273.21	4.45	—	—	—	SCS
	do	do	do	—	—	July 1957	6.39	1,217.58	4.26	95.7	2.27	4,731	
	do	do	do	—	—	Sept. 1961	4.19	1,152.23	4.03	—	4.06	5,501	
	do	do	do	—	—	July 1966	4.81	1,127.06	3.94	*80	1.36	1,980	
50-30b	Sandstone Site No. 6	Sandstone	do	6.46	5.24	Apr. 1951	—	1,956.05	4.12	—	—	—	SCS
	do	do	do	—	—	Oct. 1962	11.53	1,813.2	3.82	70.7	2.36	3,634	
	do	do	do	—	—	Sept. 1967	4.96	1,806.22	3.80	*72	.27	529	
50-31a	Sandstone Site No. 9	do	do	3.50	3.46	Mar. 1951	—	1,275.09	4.94	—	—	—	SCS
	do	do	do	—	—	Oct. 1957	6.58	1,217.59	4.72	75.78	2.52	4,160	
	do	do	do	—	—	Oct. 1962	5.0	1,178.72	4.57	79.4	2.20	4,148	
	do	do	do	—	—	Sept. 1967	4.93	1,175.25	4.56	*80	.20	436	
50-32b	Sandstone Site No. 10A	Washita	do	2.87	2.80	Apr. 1951	—	1,066.02	6.23	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	5.50	1,018.8	6.06	79.3	1.77	3,057	
	do	do	do	—	—	Sept. 1961	4.90	963.9	5.62	82.8	5.46	9,996	
	do	do	do	—	—	July 1966	4.80	888.0	5.29	*75	4.16	5,627	
50-33b	Sandstone Site No. 14	do	do	1.02	1.00	Sept. 1951	—	315.15	4.85	—	—	—	SCS
	do	do	do	—	—	May 1960	8.68	288.09	4.43	93.08	3.12	6,320	
	do	do	do	—	—	Aug. 1965	5.25	286.79	4.40	68.1	.25	371	
	do	do	do	—	—	July 1970	4.98	275.82	4.24	*75	2.20	3,611	
50-34b	Sandstone Site No. 16	do	do	11.47	11.28	Aug. 1952	—	4,463.43	7.29	—	—	—	SCS
	do	do	do	—	—	July 1957	4.92	4,294.49	7.02	77.94	3.04	5,161	
	do	do	do	—	—	Sept. 1961	4.21	4,164.87	6.81	74.85	2.73	4,209	
	do	do	do	—	—	Aug. 1966	4.86	4,038.34	6.60	*76	2.31	3,874	
50-35b	Sandstone Site No. 16A	do	Cheyenne, Okla.	8.78	5.11	Dec. 1951	—	2,065.88	4.41	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	4.82	2,033.89	4.35	80.6	1.30	2,281	
	do	do	do	—	—	Sept. 1961	4.88	1,987.93	4.25	79.79	1.84	3,181	
	do	do	do	—	—	Aug. 1966	4.86	1,979.45	4.23	*77	.34	602	
50-36b	Sandstone Site No. 17	Currant Creek	do	10.13	10.04	Aug. 1951	—	3,584.9	5.53	—	—	—	SCS
	do	do	do	—	—	Oct. 1956	5.13	3,465.8	5.35	70.4	2.31	3,540	
	do	do	do	—	—	Oct. 1960	4.04	3,322.4	5.13	59	3.53	5,418	
	do	do	do	—	—	Aug. 1965	4.79	3,292.7	5.08	59	.62	797	
	do	do	do	—	—	June 1970	4.91	3,276.0	5.06	*60	.34	526	
50-37a	Sandstone Site No. 22	Sandstone	do	2.25	2.20	Aug. 1951	—	970.7	6.14	—	—	—	SCS
	do	do	do	—	—	Oct. 1957	6.16	942.12	5.97	81.53	2.08	3,696	
	do	do	do	—	—	Oct. 1962	5.0	913.51	5.78	79.4	2.64	4,445	
	do	do	do	—	—	Sept. 1967	4.96	873.9	5.63	*83	3.63	7,036	
50-38	Stickley Pond No. 4	Canadian River	Canadian, Tex.	.171	.171	Jan. 1947	—	15.794	.329	—	—	—	SCS
	do	do	do	—	—	Apr. 1958	11.266	13.963	.290	77.65	.959	1,621.88	
50-39	Stickley Pond No. 6	do	do	.162	.162	Oct. 1945	—	21.035	.438	—	—	—	SCS
	do	do	do	—	—	Apr. 1958	12.564	16.627	.346	85.34	2.167	4,027.81	
50-40	Wheeler Farm Pond	do	do	.205	.205	Dec. 1944	—	7.353	.197	—	—	—	SCS
	do	do	do	—	—	Apr. 1958	13.33	6.673	.179	82.73	.249	448.66	
50-41b	Whiteshield Creek Site No. 4	Washita	Elk City, Okla.	.62	.60	Jan. 19[illegible]	—	223.4	4.33	—	—	—	SCS
	do	do	do	—	—	Sept. 1959	10.70	207.7	4.02	75.68	2.45	4,038.4	
	do	do	do	—	—	Aug. 1964	4.91	199.6	3.87	75.68	2.75	4,532.9	
	do	do	do	—	—	June 1969	4.85	179.9	3.49	*75	6.77	10,872	
50-42b	Wildhorse Site No. 1	Wildhorse	Davis, Okla.	.97	.95	May 1949	—	242.4	1.11	—	—	—	SCS
	do	do	do	—	—	July 1959	10.25	236.2	1.08	61	.63	834.1	
	do	do	do	—	—	Oct. 1963	4.25	233.8	1.07	61	.60	796.4	
	do	do	do	—	—	July 1968	4.82	229.3	1.05	*61	.98	1,274.6	
50-43a	Wildhorse Creek Site No. 33	do	Duncan, Okla.	1.77	1.73	Mar. 1950	—	587.38	1.780	—	—	—	SCS
	do	do	do	—	—	Sept. 1960	10.50	566.24	1.716	85	1.16	2,147	
	do	do	do	—	—	Aug. 1965	4.95	548.66	1.663	74	2.05	3,306	

50-44b	Owl Creek No. 1	Owl Creek	Wayne, Okla.	.61	.59	Apr.	1949	—	206.3	.91	—	—	—	SCS
	do	do	do	—	—	Aug.	1959	10.32	200.0	.88	65.5	1.07	1,527.2	
	do	do	do	—	—	Oct.	1963	4.12	194.0	.86	65.5	2.03	3,166.6	
	do	do	do	—	—	Aug.	1968	4.84	190.3	.84	*63	1.29	1,721.1	
50-45a	Chigley Sandy Site No. 4	Washita	Wynnewood, Okla.	3.80	3.73	Aug.	1955	—	1,075.3	1.24	—	—	—	SCS
	do	do	do	—	—	Mar.	1958	2.62	1,054.8	1.21	51.61	2.10	2,361	
	do	do	do	—	—	Oct.	1963	5.52	1,018.0	1.17	51.61	1.79	2,012	
	do	do	do	—	—	July	1969	5.76	966.7	1.11	*59	2.39	3,454	
50-46	Flood Retarding Structure No. 2 Rush Cr. Watershed	Rush Creek	Rush Springs, Okla.	2.13	2.05	Aug.	1959	—	655.99	1.929	—	—	—	SCS
	do	do	do	—	—	July	1965	5.90	639.60	1.881	77.75	1.36	2,303	
50-47a	Barnitz No. 14	Barnitz	Clinton, Okla.	4.22	4.11	Nov.	1958	—	1,723.2	4.28	—	—	—	SCS
	do	do	do	—	—	Sept.	1963	4.85	1,645.9	4.08	*70	3.87	5,900	
	do	do	do	—	—	Aug.	1968	4.87	1,633.9	4.05	*70	.61	877.9	
50-48	Sugar Creek Site No. 13	Sugar Creek	Hinton, Okla.	1.99	1.93	Feb.	1964	—	532.17	2.137	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	1.70	503.79	2.023	82.27	8.65	15,499	
50-49	Upper Washita River Site #25	Washita River	Canadian, Tex.	7.14	6.96	Nov.	1961	—	1,315.92	4.62	—	—	—	SCS
	do	do	do	—	—	July	1966	4.6	1,312.74	4.61	91.8	1/.10	1/199.9	
50-50	Kent Creek Watershed Site #1	Kent Creek	Quitaque, Tex.	1.52	1.46	Apr.	1964	—	622.01	15.4	—	—	—	SCS
	do	do	do	—	—	June	1966	2.1	613.83	15.2	61	1/2.67	1/3.547	
50-51	Rush Creek No. 2	Rush Creek	Rush Springs, Okla.	2.13	2.05	Aug.	1959	—	656.0	2.31	—	—	—	SCS
	do	do	do	—	—	July	1965	5.9	639.6	2.25	77.75	1.36	2,303	
	do	do	do	—	—	Sept.	1970	5.19	635.4	2.24	*77	.39	654	
50-52	Saddle Mountain No. 2	Saddle Mountain Creek	Carnegie, Okla.	3.43	3.37	Apr.	1959	—	771.3	2.11	—	—	—	SCS
	do	do	do	—	—	Apr.	1965	6	2/—	—	38	2/.47	2/309	
	do	do	do	—	—	Sept.	1970	5.26	751.4	2.05	*60	.53	734	

SABINE, NECHES, AND TRINITY RIVER BASINS

51-1	Terrell City Lake	Kings Creek	Terrell, Tex.	9.30	8.71	Oct.	1921	—	2,219	—	—	—	—	SCS
	do	do	do	—	—	Dec.	1949	28.25	1,605	—	59.2	2.49	3,211	
51-2	Lower Benton Lake	Trib. of Elm Creek	Corsicana, Tex.	.91	.82	—	1895*	—	319	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1949	54	205	—	—	2.57	—	
51-3	Burke Neck Lake	do	do	.58	.54	—	1880	—	181	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1949	69	92	—	—	2.39	—	
51-4	Lake Dallas	Elm Fk.of Trinity River	Denton, Tex.	1,174	1,157	Feb.	1928	—	180,759	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1938	10.5	167,072	—	53	1.13	1,304	
51-5	Lake Halbert	Elm Creek	Corsicana, Tex.	3/9.48	8.56	—	1921	—	8,012	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1949	28	6,657	—	67.4	5.66	8,308	
51-6	Magnolia Lake (Red Horse)	Trib. of Elm Creek	do	.59	.43	—	1885	—	756	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1949	64	699	—	—	3.53	—	
51-7	Mountain Creek	Mountain Creek	Dallas, Tex.	280	274.4	Mar.	1937	—	37,520	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1946	9.7	27,100	—	—	3.91	—	
51-8b	White Rock Lake	White Rock Creek	do	99.1	97.4	Apr.	1910	—	18,158	.80	—	—	—	SCS
	do	do	do	—	—	Apr.	1935	25	14,276	.63	49	1.60	1,708	
	do	do	do	—	—	Mar.	1956	20.9	12,321	.54	35	.97	151	
	do	do	do	—	—	Oct.	1970	14.6	10,743	.47	32	1.11	505	
51-9	Grand Saline	Simmons Branch	Grand Saline, Tex.	2.12	2.02	Feb.	1925	—	531	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1938	13.25	509	—	38.7	.82	692	
51-10	T & P	Town Creek	Weatherford, Tex.	6.24	6.18	—	1930	—	370	—	—	—	—	SCS
	do	do	do	—	—	Nov.	1938	8.5	328	—	61	.796	1,058	
51-11	Lake Clark	Waxahachie Creek	Ennis, Tex.	3.14	2.87	—	4/	—	5/2,085	—	—	—	—	SCS
	do	do	do	—	—	Dec.	1950	—	5/1,761	—	*50	5/2.60	2,831	
51-12	Kemp City	Cedar Creek	Kemp, Tex.	1.48	1.42	June	1926	—	376	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	12.8	298	—	—	4.29	—	
51-13	Variety Club Boys' Ranch Lake	Unnamed trib.	Bedford, Tex.	.30	.29	June	1942	—	38	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1950	7.8	33	—	—	2.21	—	
51-14	Wills Point	Mugbee Creek	Wills Point, Tex.	1.83	1.75	Sept.	1914	—	396	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1938	23.6	275	—	60.1	2.93	3,035	
51-15	Bridgeport	West Fork of Trinity River	Bridgeport, Tex.	1,051	1,033	—	1932	—	6/292,000	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1943	10.8	283,260	—	—	.785	—	
51-16a	Eagle Mountain	do	Fort Worth, Tex.	1,875	7/809	Mar.	1934	—	6/211,000	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1939	5	205,175	—	—	1.44	—	
	do	do	do	—	—	Nov.	1952	13	182,000	—	—	2.20	—	
51-17	Lake Erie	Unnamed trib.	do	1.05	1.01	—	1899	—	270	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	40	204	—	—	1.63	—	
51-18	Mabank City Lake	Trib. of Cedar Creek	Athens, Tex.	.36	.33	—	1926	—	295	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	13	271	—	—	5.51	—	
51-19	Wolf Creek	Wolf Creek	Palestine, Tex.	2.55	2.50	—	1919	—	222	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1939	20	199	—	—	.46	—	
51-20	Elkins Lake	East Sandy Creek	Huntsville, Tex.	3.18	3.05	—	1930	—	856	—	—	—	—	SCS
	do	do	do	—	—	July	1950	20	812	—	—	.72	—	

1/ Sediment pool only.
2/ Area above sediment pool riser was not surveyed in 1965.
3/ Excludes area above two lakes in watershed which contributes occasional flow to Lake Halbert.
4/ Lake Clark was built in 1940 downstream from "Ennis New Lake" or "Club Lake" which was built in 1895. Club Lake and a small pond now submerged by Lake Clark.
5/ Data based upon combined capacities, drainage area, and sediment volumes of all lakes in system.
6/ Water supply pool capacity. Does not include surcharge or flood storage.
7/ Excludes area above Bridgeport Reservoir which lies upstream from Eagle Mt. Reservoir.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
SABINE, NECHES, AND TRINITY RIVER BASINS (Continued)													
51-21	Murphy Lake	East Fork of Trinity River	Crandall, Tex.	4.09	3.98	Oct. 1922	—	397	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1939	16.5	138	—	*60	3.94	5,150	
51-22	Loring Lake	Trib. of Herrican Creek	Zwolle, La.	1.05	.95	Sept. 1928	—	663	.789	—	—	—	SCS
	do	do	do	—	—	Sept. 1954	26	623	.742	85.08	1.62	3,002	
51-23	Kerens City Lake	Cow Creek	Kerens, Tex.	6.42	6.28	Sept. 1935	—	630	.237	—	—	—	SCS
	do	do	do	—	—	July 1954	18.8	554	.208	54.49	.64	759	
51-24	Variety Club Lake	Trib. of Trinity River	Bedford, Tex.	.29	.29	July 1942	—	38	*.491	—	—	—	SCS
	do	do	do	—	—	May 1950	7.8	33	*.426	—	2.21	—	
51-25a	Clear Fk. Watershed Site No. 10.	Trinity River	Weatherford, Tex.	4.30	4.25	Oct. 1955	—	1,473.49	1.90	—	—	—	SCS
	do	do	do	—	—	Apr. 1963	7.5	1,430.91	1.84	—	—	—	
	do	do	do	—	—	May 1968	5.1	1,411.04	1.82	86	.92	1,682	
51-26b	Honey Creek Site No. 11	Honey Creek	McKinney, Tex.	[illegible]	1.92	Feb. 1952	—	1,291.0	1.89	—	—	—	SCS
	do	do	do	—	—	Apr. 1962	10.2	1,201.8	1.76	—	—	—	
	do	do	do	—	—	July 1967	5.3	1,186.7	1.74	[illegible]1.9	1.48	3,956	
51-27b	Honey Creek Site No. 12	Trib. E. Fork Trinity	do	1.28	1.26	Jan. 1952	—	553.33	1.27	—	—	—	SCS
	do	do	do	—	—	July 1969	17.5	475.52	1.09	60.72	3.53	3,130	
51-28a	Dawson City Lake	Trib. of Richland Creek	Dawson, Tex.	1.16	1.07	Apr. 1937	—	610	1.473	—	—	—	SCS
	do	do	do	—	—	Feb. 1956	18.8	466	1.126	—	7.16	5,130	
	do	do	do	—	—	Sept. 1963	7.5	390.1	.962	—	9.46	6,387	
51-29	Lake Cherokee	Sabine River	Longview, Tex.	170.00	163.77	Oct. 1948	—	49,295	.426	—	—	—	SCS
	do	do	do	—	—	Apr. 1960	11.5	46,705	.412	83.12	1.37	2,680	
51-30	Lavon Reservoir	East Fork Trinity River	Lavon, Tex.	777.0	745.7	— 1945 1/	—	423,400	1.329	—	—	—	CE
	do	do	do	—	—	Oct. 1953 2/	0	434,450	1.363	—	—	—	
	do	do	do	—	—	Oct. 1959	6.0	425,960	1.337	53.1	1.90	2,197	
51-31a	Site No. 11B Elm Fk. Watershed	Trinity River	Gainesville, Tex.	2.00	1.87	Nov. 1958	—	678.2	1.33	—	—	—	SCS
	do	do	do	—	—	July 1963	4.67	670.0	1.31	3/78.3	.96	3/1,637	
	do	do	do	—	—	Oct. 1968	5.25	654.6	1.28	87	1.57	2,402	
51-32	Garza-Little Elm Reservoir (Lewisville Dam).	Elm Fork of Trinity River	Lewisville, Tex.	1,660	1,599	— 1946	—	1,016,200	2.311	—	—	—	CE
	do	do	do	—	—	— 1952 4/	—	1,002,900	2.281	—	—	—	
	do	do	do	—	—	Nov. 1954 5/	—	1,003,400	2.282	—	—	—	
	do	do	do	—	—	Sept. 1960	5.88	989,728	2.251	50.6	1.46	1,609	
51-33	Dam B Reservoir	Neches	Jasper, Tex.	6/7,573	7,546.6	— 1947	—	124,700	.032	—	—	—	CE
	do	do	do	—	—	— 1951	—	7/131,142	.034	—	—	—	
	do	do	do	—	—	Feb. 1960	8.83	131,681	.034	60.9	8/.025	8/33.16	
51-34	Clear Creek Watershed Site No. 21.	Trinity River	Muenster, Tex.	1.54	1.46	May 1962	—	479.4	1.37	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	5.19	468.8	1.36	—	1.40	—	
51-35	Upper Lake Fk. Watershed Site 23	Sabine River	Sulphur Springs, Tex.	9.39	8.80	Aug. 1962	—	3,303.5	.69	—	—	—	SCS
	do	do	do	—	—	Oct. 1967	5.2	3,282.9	.69	—	.45	652	
51-36	Lake Amon G. Carter	Big Sandy Creek	Bowie, Tex.	103	101	May 1956	—	15,805.75	1.07	—	—	—	SCS
	do	do	do	—	—	May 1967	11	15,238.06	1.03	55.19	.51	613	
51-37	Chambers Creek Site 37	Trinity River	Cleburne, Tex.	2.05	1.95	Dec. 1960	—	624.84	1.34	—	—	—	SCS
	do	do	do	—	—	Sept. 1964	3.8	619.37	1.33	—	—	—	
	do	do	do	—	—	May 1969	4.7	617.89	1.33	49	.16	448	
51-38	Chambers Creek Site 101-A	do	Frost, Tex.	2.58	2.34	Apr. 1960	—	1,152.11	1.20	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	4.5	1,137.61	1.18	—	—	—	
	do	do	do	—	—	Sept. 1968	3.9	1,114.89	1.16	54.9	2.49	2,806	
51-39	Clear Fork Watershed Site No. 7.	do	Poolville, Tex.	2.55	2.44	Oct. 1955	—	746.9	1.57	—	—	—	SCS
	do	do	do	—	—	Apr. 1969	13.5	626.29	1.32	47.2	3.66	3,760	
51-40	Denton Creek Watershed Site No. 17.	do	Decatur, Tex.	4.10	3.94	Oct. 1963	—	1,621.33	2.7	—	—	—	SCS
	do	do	do	—	—	Oct. 1968	5	1,557.16	2.6	—	3.26	—	
51-41	East Keechi Creek Site No. 1	Brazos River	Jacksboro, Tex.	6.63	6.30	Jan. 1964	—	1,845.56	1.76	—	—	—	SCS
	do	do	do	—	—	June 1968	4.4	1,827.15	1.74	*72	.66	1,035	
LOWER BRAZOS, LOWER COLORADO, GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS													
52-1	Lake Corpus Christi	Nueces River	Mathis, Tex.	16,800	16,791	July 1934	—	54,426	.080	—	—	—	SCS
	do	do	do	—	—	Mar. 1942	7.6	43,801	.064	34.9	.083	63	
	do	do	do	—	—	Mar. 1948	6.0	39,387	.058	35.6	.044	36	
52-2	Medina Lake	Medina River	San Antonio, Tex.	587	578	Mar. 1913	—	274,065	—	—	—	—	SCS
	do	do	do	—	—	Jan. 1937	23.9	267,630	—	61.1	.465	619	
	do	do	do	—	—	May 1948	11.3	265,075	—	75.0	.391	—	

52-3	Buchanan	Colorado River	Burnet, Tex.	9/19,350	19,313	June	1937	—	970,010	*.649	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	3.7	954,859	*.639	—	.21	—	
52-4	Moss Ranch Stock Pond	S. Bull Creek	Llano, Tex.	.07	.07	—	1909	—	4.7	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	32	4.5	—	—	.07	—	
52-5	Moss Ranch Stock Pond	W. Bull Creek	do	.20	.19	—	1903	—	9.3	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	38	9.1	—	—	.021	—	
52-6	Helms Tank	Trib. of Sandy Creek	do	.15	.14	—	1916	—	12	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	25	11.6	—	—	.12	—	
52-7	Baker Lake	Trib. of San Antonio River	Somerset, Tex.	3.17	3.10	Sept.	1950	—	251	.595	—	—	—	SCS
	do	do	do	—	—	Aug.	1955	4.95	228	.540	34.65	1.50	1,132	
52-8a	Calaveras Creek Site No. 6	Calaveras Creek	San Antonio, Tex.	7.01	6.70	Dec.	1956	—	1,697.82	1.65	—	—	—	SCS
	do	do	do	—	—	Mar.	1968	11.25	1,661.12	1.62	66.17	.49	706	
52-9	Escondido No. 11	Trib. of Escondido Creek	Kenedy, Tex.	8.43	7.94	July	1958	—	2,728.0	2.022	—	—	—	SCS
	do	do	do	—	—	July	1960	2.0	2,667.8	1.978	47.08	3.79	3,886	
52-10	Rudder Pond	Trib. of Llano River	Hext, Tex.	1.35	1.34	Aug.	1951	—	11.96	.082	—	—	—	SCS
	do	do	do	—	—	Aug.	1955	4	11.45	.078	—	.09	—	
52-11	Sirianni Lake	Trib. of Hondo Creek	Moore, Tex.	.769	.747	Feb.	1951	—	80.3	1.959	—	—	—	SCS
	do	do	do	—	—	Sept.	1955	4.54	76.5	1.866	45.6	1.12	1,112	
52-12	Smith Pond	Trib. of Benito Creek	Jourdanton, Tex.	.191	.188	Apr.	1953	—	6.41	.361	—	—	—	SCS
	do	do	do	—	—	Aug.	1955	2.4	5.60	.315	27.8	1.80	1,090	
52-13	Thornton Lake	Cibalo Creek	Boerne, Tex.	1.54	1.52	Sept.	1952	—	142.4	.578	—	—	—	SCS
	do	do	do	—	—	Aug.	1955	2.91	135.2	.549	—	1.64	—	
52-14	Eley Lake	Guadalupe River	Gonzales, Tex.	2.34	2.32	Jan.	1949	—	10/48.97	.078	—	—	—	SCS
	do	do	do	—	—	June	1964	15.42	43.75	.070	28.3	.15	92	
52-15	Blackwell Lake	Trib. of Deer Creek Guadalupe River Basin.	Cuero, Tex.	2.76	2.75	Sept.	1949	—	10/45.12	.061	—	—	—	SCS
	do	do	do	—	—	June	1964	14.75	41.51	.056	49.6	.09	97	
52-16a	Site No. 1 Escondido Creek	San Antonio River	Kenedy, Tex.	3.01	2.83	Sept.	1954	—	924.7	2.30	—	—	—	SCS
	do	do	do	—	—	June	1964	9.8	906.2	2.26	—	.67	3/763	
	do	do	do	—	—	July	1969	5.1	890.1	2.22	—	1.12	1,710	
52-17	Cummings Creek Watershed Site No. 6.	Trib. Cummings Creek	Giddings, Tex.	2.99	2.76	Aug.	1958	—	858.3	.77	—	—	—	SCS
	do	do	do	—	—	Sept.	1963	5.1	855.2	.77	—	.22	—	
	do	do	do	—	—	Aug.	1969	5.9	854.1	.76	—	.07	—	

BRAZOS RIVER BASIN (SOUTH BEND TO WASHINGTON) MIDDLE, AND COLORADO RIVER BASINS

53-1	Lake Scarborough	Trib. of Jim Ned Creek	Coleman, Tex.	10.8	10.6	May	1923	—	2,153	—	—	—	—	SCS
	do	do	do	—	—	May	1940	17	2,007	—	51.41	.81	907	
53-2	Santa Anna Lake	Mud Creek	Santa Anna, Tex.	1.17	1.05	May	1923	—	766	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1940	17	745	—	45.2	1.18	1,162	
53-3	Lake Eanes	Mercer Creek	Comanche, Tex.	13.76	13.57	May	1926	—	1,313	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1946	20.3	1,221	—	—	.334	—	
53-4	Lake Merritt	Browns Creek	Goldthwaite, Tex.	11.65	11.50	May	1917	—	962	—	—	—	—	SCS
	do	do	do	—	—	May	1940	23	855	—	43	.40	375	
53-5	Hubbard City Lake No. 3	Trib. of E. Cottonwood Cr.	Hubbard, Tex.	.16	.14	—	1913	—	11/104.5	—	—	—	—	SCS
	do	do	do	—	—	May	1949	36	90.2	—	—	2.06	—	
53-6	Hubbard City Lake No. 4	E. Cottonwood Creek	do	1.40	1.35	—	1917	—	11/318.2	—	—	—	—	SCS
	do	do	do	—	—	May	1949	32	255.4	—	—	1.45	—	
53-7a	Rogers Lake	Trib. of Little River	Rogers, Tex.	.55	.51	Fall	1922	—	164	—	—	—	—	SCS
	do	do	do	—	—	Sept.	1934	12	126.5	—	—	6.12	—	
53-8	Hubbard City Lake No. 1	Trib. E. Cottonwood Creek	Hubbard, Tex.	.5	.5	—	1898	—	12/110	—	—	—	—	SCS
	do	do	do	—	—	May	1949	51	84	—	—	1.0	—	
53-9	Hubbard City Lake No. 2	do	do	.03	.03	—	1912	—	12/36.3	—	—	—	—	SCS
	do	do	do	—	—	May	1949	37	33.0	—	—	3.0	—	
53-10	Hubbard City Lake No. 5	East Cottonwood Creek	do	.11	.10	—	1925	—	44.8	—	—	—	—	SCS
	do	do	do	—	—	May	1949	24	37.8	—	—	3.0	—	
53-11	Lake Lawn	Redbank Creek	Lawn, Tex.	13.0	12.8	—	1911	—	530	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1941	30	354	—	—	.46	—	
53-12	Lometa	Salt & Emory Creeks	Lometa, Tex.	4.74	4.60	—	1912	—	759	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	29	732	—	—	.20	—	
53-13	Meridian Lake	Bee Creek	Meridian, Tex.	3.30	3.20	—	1934	—	723	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1948	14	692	—	—	.69	—	
53-14	Miller Lake	Trib. of Horse Creek	San Saba, Tex.	.41	.38	Sept.	1913	—	83	—	—	—	—	SCS
	do	do	do	—	—	Mar.	1941	27.5	75	—	—	.71	—	
53-15	Odell Lake	Unnamed trib.	Hubbard, Tex.	.56	.55	July	1925	—	75.1	—	—	—	—	SCS
	do	do	do	—	—	July	1949	24	52.6	—	—	1.71	—	
53-16	Possum Kingdom Lake	Brazos River	Graford, Tex.	13/14,098	12,955	May	1941	—	729,985	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1949	7.75	672,420	—	—	.57	—	
53-17	Rock Crusher	Bachelor Creek	Coleman, Tex.	16.5	16.48	—	1910	—	153	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	31	80	—	—	.14	—	
53-18	Old Santa Anna City Lake	Mukewater Creek	Santa Anna, Tex.	.90	.87	Jan.	1910	—	153	—	—	—	—	SCS
	do	do	do	—	—	June	1940	30.5	118	—	—	1.31	—	

1/ Original capacity from map by stereo photogrammetric methods.
2/ "Original" or 1945 capacity adjusted in 1961 by range line controls established in 1953 give "Oct. 53" area and capacity.
3/ Sediment pool only.
4/ Adjusted for 1952 survey of Lake Dallas.
5/ Adjusted in Apr. 1963 for detailed range survey in 1952-53-54.
6/ Determined by USGS Nov. 1961.
7/ 1951 adjusted data.
8/ Deposits above Highway 190 bridge only. Not corrected for degradation between highway and dam.
9/ Drainage area is 31,250 sq. mi., of which 11,900 sq. mi. are noncontributing.
10/ Original capacity determined by spudding on 1964 survey.
11/ Dam was raised in 1925 and 1949. Capacities based on 1949 level.
12/ Dam was raised in 1925. Capacity based on 1925 level.
13/ Includes 1,111 sq. mi. of partially contributing drainage above lakes in watershed; excludes 8,900 sq. mi. of noncontributing drainage at head of watershed.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
						BRAZOS RIVER BASIN (SOUTH BEND TO WASHINGTON) MIDDLE, AND COLORADO RIVER BASINS (Continued)							
53-19	Old Coleman City Lake	Home Creek	Coleman, Tex.	0.73	0.69	Nov. 1906	—	289	—	—	—	—	SCS
	do	do	do	—	—	May 1940	33.6	273	—	—	0.67	—	
53-20	Hamilton City Lake	Two Mile Creek	Hamilton, Tex.	12.0	11.9	June 1923	—	610	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1941	17.75	560	—	—	.24	—	
53-21	Lake Leon	Leon River	Eastland, Tex.	225	224.7	June 1920	—	1/1,637	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1941	20.75	1,275	—	—	.08	—	
53-22	Lake Mineral Wells	Rock Creek	Mineral Wells, Tex.	74.4	73.4	— 1922	—	10,741	—	—	—	—	SCS
	do	do	do	—	—	Dec. 1941	19.5	9,032	—	—	1.19	—	
53-23	Buffalo Tank (Knox Tank)	Trib. of Pecan Bayou	Coleman, Tex.	1.73	1.71	— 1900	—	33	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1941	41	29	—	—	.058	—	
53-24	R. G. Hollingsworth Stock Pond.	do	do	2.60	2.58	June 1937	—	20	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1941	3.7	14	—	—	.66	—	
53-25	J. S. Wall Stock Pond	Trib. of Brady Creek	Brady, Tex.	.35	.35	— 1927	—	13	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1941	14	12.2	—	—	.16	—	
53-26	White Tank	Trib. of Pecan Bayou	Brownwood, Tex.	.80	.80	May 1936	—	4.5	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1941	4.8	3.6	—	—	.24	—	
53-27	Zimmerlee Stock Pond (North)	Trib. of Jim Ned Creek	Lawn, Tex.	.13	.13	— 1916	—	1.12	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1941	25	.80	—	—	.10	—	
53-28	Stith Lake	Redbank Creek	do	1.04	1.01	Aug. 1926	—	102	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1941	14.6	93	—	—	.63	—	
53-29	Philpeco Lake	Paint Creek	Pioneer, Tex.	9.04	9.00	Apr. 1925	—	183	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1941	15.9	173	—	—	.07	—	
53-30b	Lake Brownwood	Pecan Bayou (Colo. River)	Brownwood, Tex.	1,544	1,533	July 1932	—	149,925	1.011	—	—	—	SCS
	do	do	do	—	—	Feb. 1940	7.6	145,720	.983	41.9	.361	329	
	do	do	do	—	—	Sept. 1959	19.6	135,963	.917	42.2	.325	299	
53-31a	Lake Waco (Old)	Bosque	Waco, Tex.	2/1,649	2/1,645	Apr. 1930	—	39,378	—	—	—	—	CE
	do	do	do	—	—	Feb. 1935	4.9	33,717	—	*58.5	.695	886	
	do	do	do	—	—	Feb. 1936	1.0	31,588	—	*58.5	1.28	1,631	
	do	do	do	—	—	Dec. 1947	11.8	22,026	—	*58.5	.487	621	
	do	do	do	—	—	Dec. 1964	17.0	15,427	—	—	.236	—	
53-32	Lake Eddleman	Flint Creek	Graham, Tex.	42	41.4	Feb. 1929	—	6,583	1.144	—	—	—	SCS
	do	do	do	—	—	May 1954	25.25	5,917	1.028	69.2	.64	687	
53-33b	Site No. 3 Cow Bayou	Brazos	Moody, Tex.	1.40	1.32	Nov. 1955	—	458.5	1.23	—	—	—	SCS
	do	do	do	—	—	Aug. 1960	4.75	393.3	1.05	—	10.40	—	
	do	do	do	—	—	Aug. 1965	5.04	375.4	1.00	—	2.69	—	
	do	do	do	—	—	Apr. 1970	4.69	366.7	.98	—	1.41	1,572	
53-34a	Cow Bayou No. 4	Foster Creek	Waco, Tex.	5.25	5.20	July 1956	—	1,915	1.24	—	—	—	SCS
	do	do	do	—	—	Sept. 1969	13.2	1,833.53	1.19	—	1.19	1,419	
53-35	Deep Creek No. 3	Trib. of Deep Creek	Brady, Tex.	3.42	3.19	Nov. 1953	—	925.18	2.821	—	—	—	SCS
	do	do	do	—	—	Aug. 1960	6.8	881.80	2.688	76.57	2.00	3,335	
53-36a	Green Creek No. 1	Green Creek	Dublin, Tex.	3.57	3.38	Apr. 1955	—	1,095	1.98	—	—	—	SCS
	do	do	do	—	—	Jan. 1957	1.8	1,080	1.96	—	—	—	
	do	do	do	—	—	Apr. 1962	5.2	1,065	1.93	—	—	—	
	do	do	do	—	—	June 1967	5.2	1,063	1.93	73.6	.11	3/88	
53-37	Silver Lake	N. E. Trib. of Leon River	do	.37	.334	— 1910	—	153.8	2.435	—	—	—	SCS
	do	do	do	—	—	July 1960	50	145.0	2.296	—	.527	—	
53-38	Main Res. Deep Creek Site 5	Colorado	Brady, Tex.	2.91	2.72	Aug. 1953	—	1,326.7	4.755	—	—	—	SCS
	do	do	do	—	—	July 1961	7.9	1,295.7	4.644	—	1.44	—	
53-39	Upper Res. Deep Creek Site 5	do	do	2.19	2.18	Aug. 1953	—	15.2	.072	—	—	—	SCS
	do	do	do	—	—	July 1961	7.9	11.2	.053	69.9	.23	290	
53-40a	Mukewater Creek Site No. 9	Mid. Colorado River	Bangs, Tex.	6.75	6.55	Jan. 1961	—	732.94	1.38	—	—	—	SCS
	do	do	do	—	—	June 1965	4.42	708.42	1.33	—	1.22	—	
	do	do	do	—	—	July 1970	5.1	703.41	1.32	—	.22	—	
53-41a	Sulphur Creek Site 3	Lampasas River	Lampasas, Tex.	10.81	10.58	Dec. 1959	—	3,229.2	1.6	—	—	—	SCS
	do	do	do	—	—	Nov. 1962	2.8	3,224.7	1.6	—	—	—	
	do	do	do	—	—	Aug. 1968	5.8	3,223.3	1.6	55	3/.02	3/24	
53-42	Whitney Reservoir	Brazos River	Whitney, Tex.	4/17,656	5/3,480	Dec. 1941	—	6/2,013,600	—	—	—	—	CE
	do	do	do	—	—	Apr. 1959	7.4	1,999,500	—	62.6	.55	749.88	
53-43	Site No. 8 Deep Creek	Dry Prong	Brady, Tex.	4.26	4.02	Dec. 1951	—	1,409.81	2.70	—	—	—	SCS
	do	do	do	—	—	Sept. 1966	14.8	1,367.81	2.62	—	.71	—	
53-44	Site No. 10-A Mukewater Creek	Mukewater Creek	Bangs, Tex.	15.26	14.59	Mar. 1965	—	3,164.89	1.85	—	—	—	SCS
	do	do	do	—	—	Aug. 1966	1.4	3,157.99	1.85	—	.34	—	
53-45	Lake Daniel	Gonzales Creek	Breckenridge, Tex.	115	113	June 1949	—	10,731	.81	—	—	—	SCS
	do	do	do	—	—	Nov. 1970	21.4	9,515	.72	68	.49	512	
53-46	Site 9 Lower San Saba River	Colorado River	San Saba, Tex.	3.03	2.88	Jan. 1960	—	645.79	1.60	—	—	—	SCS
	do	do	do	—	—	Sept. 1967	7.87	635.49	1.57	—	.46	723	

UPPER BRAZOS AND UPPER COLORADO RIVER BASINS

54-1	Lake Abilene	Elm Creek	Abilene, Tex.	98.5	97.5	Aug. 1921	—	10,325	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1948	27	9,786	—	*60	.21	274	
54-2b	Lake Nasworthy	South Concho	San Angelo, Tex.	3,294	3,119	Oct. 1930	—	11,485	*.046	—	—	—	SCS
	do	do	do	—	—	Dec. 1938	8.2	10,294	*.041	67.5	.046	68	
	do	do	do	—	—	May 1953	14.5	7/12,628	*.051	67.5	.023	34	
54-3	Lake Sweetwater	Bitter Creek	Sweetwater, Tex.	110	108.8	Feb. 1930	—	13,810	—	—	—	—	SCS
	do	do	do	—	—	Dec. 1941	11.8	13,287	—	—	.41	—	
54-4	Lake Kirby	Cedar Creek	Abilene, Tex.	44	42.8	Sept. 1928	—	8,133	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1941	13.2	7,618	—	—	.51	—	
54-5	Lake Throckmorton	South Elm River	Throckmorton, Tex.	11.54	11.32	Sept. 1918	—	8/1,947	1.534	—	—	—	SCS
	do	do	do	—	—	June 1954	35.7	1,829	1.441	31.55	.29	199	
54-6a	Lake Fort Phantom Hill	Elm Fork, Brazos River	Abilene, Tex.	478	268	Oct. 1938 9/	—	76,966	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1953	14.8	74,312	—	35.99	.67	525	
54-7	Mountain Creek	Mountain Creek	Robert Lee, Tex.	32.00	31.88	May 1950	—	945.3	.369	—	—	—	SCS
	do	do	do	—	—	Apr. 1961	10.9	804.9	.314	53.06	.40	462.17	
54-8	EQE Ranch Pond	Trib. of S. Concho River	San Angelo, Tex.	1.60	1.53	May 1937	—	276	2.240	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	18.2	250	2.029	63.6	.93	1,288	
54-9	Lake Stamford	Paint Creek	Stamford, Tex.	360	352.34	June 1953	—	57,632.35	1.71	—	—	—	SCS
	do	do	do	—	—	May 1966	12.9	53,927.57	1.60	62.56	.82	760	
54-10	Site 18 Valley Cr. Watershed	Trib. Valley Creek	Winters, Tex.	4.21	4.11	Aug. 1964	—	719.89	2.38	—	—	—	SCS
	do	do	do	—	—	June 1969	4.8	717.05	2.36	69	.14	210	
54-11	Lake Ballinger	Valley Creek	Ballinger, Tex.	210	209	Nov. 1947	—	3,872.09	.28	—	—	—	SCS
	do	do	do	—	—	Aug. 1970	22.8	3,070.42	.22	37	.17	137	
54-12	Lake Winters	Elm Creek	Winters, Tex.	63.62	63.14	Oct. 1945	—	2,518.2	.59	—	—	—	SCS
	do	do	do	—	—	July 1970	24.75	1,886.2	.44	39	.40	340	

RIO GRANDE BASIN (BELOW EAGLE PASS)

55-1	Site 6 Olmitos & Garcias Creeks	El Gato Creek	Rio Grande City, Tex.	13.19	12.94	June 1962	—	2,258.11	21.5	—	—	—	SCS
	do	do	do	—	—	Sept. 1966	4.25	2,252.03	21.4	6/75	.11	179.69	

RIO GRANDE BASIN (FORT QUITMAN TO EAGLE PASS) AND LOWER PECOS RIVER BASIN

56-1a	Cottonwood Detention	San Felipe Arroyo River	Fabens, Tex.	2.34	2.19	July 1937	—	500	16.129	—	—	—	SCS
	do	do	do	—	—	July 1954	17	378	12.154	—	3.28	—	
56-2	Rattlesnake Detention	do	do	5.15	10/2.81	July 1937	—	224.4	—	—	—	—	SCS
	do	do	do	—	—	July 1954	17	175.7	—	—	1.02	—	
56-3	Roberts Detention	do	do	2.34	2.31	July 1937	—	145.3	4.687	—	—	—	SCS
	do	do	do	—	—	July 1954	17	104.8	3.381	—	1.03	—	
56-4a	Fresa Pond	Trib. of Devils River	Sonora, Tex.	.435	.430	Dec. 1944	—	7.31	.222	—	—	—	SCS
	do	do	do	—	—	Aug. 1955	10.75	6.97	.211	69.6	.074	112	
56-5	Lowrey Draw, Site No. 9	Lowrey Draw	do	2.77	2.64	June 1961	—	3/31.1	.49	—	—	—	ABS
	do	do	do	—	—	Feb. 1969	7.65	30.84	.48	64	.01	17.5	
56-6	Lowrey Draw, Site No. 10	Trib. Lowrey Draw	do	8.43	8.20	June 1961	—	3/95	.68	—	—	—	ABS
	do	do	do	—	—	Mar. 1969	7.83	94.38	.68	64	.01	13.5	
56-7	Lowrey Draw, Site No. 12	do	do	4.38	4.19	June 1961	—	3/85.46	.68	—	—	—	ABS
	do	do	do	—	—	Feb. 1969	7.65	84.03	.67	64	.04	62.2	
56-8	Lowrey Draw, Site No. 13	do	do	1.07	1.02	June 1961	—	3/56.26	3.28	—	—	—	ABS
	do	do	do	—	—	Mar. 1969	7.74	56.10	3.26	64	.02	28.2	
56-9	Site No. 1 Diablo Arroyo	Rio Grande	McNary, Tex.	29.89	29.51	Apr. 1960	—	4,489.7	11.3	—	—	—	SCS
	do	do	do	—	—	Apr. 1965	5	4,343.1	10.9	—	—	—	
	do	do	do	—	—	Apr. 1970	5	4,235.1	10.6	—	.86	1,129.5	

1/ Dam was raised 1 ft. in 1928. Capacity at 1928 spillway level.
2/ Latest drainage area by USGS in 1964.
3/ Sediment pool only.
4/ Does not include 8,900 sq. mi. which is considered to be noncontributing to the total 26,600 sq. mi. drainage area.
5/ For the 3,558 sq. mi. area between Possum Kingdom and Whitney Dams, excluding 77.8 sq. mi. which is reservoir surface area at elevation 571.
6/ Original storage capacity 2,017,500 ac.-ft. Adjusted in 1963 for detailed range survey in 1951.
7/ Spillway raised 2.3 ft. in Sept. 1948.
8/ Dam was raised 13 ft. in 1940; capacity at 1940 spillway elevation.
9/ Date storage began has not been verified.
10/ Includes Hucco Watershed but does not include Roberts Watershed.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	RIO GRANDE BASIN (ESPANOLA TO FORT QUITMAN)												
57-1b	Elephant Butte	Rio Grande River	Elephant Butte, N. Mex.	25,923	25,866	Jan. 1915	—	2,634,800	—	—	—	—	BR
	do	do	do	—	—	Dec. 1916	1.9	2,584,865	—	—	1.02	—	
	do	do	do	—	—	Aug. 1920	3.7	2,498,850	—	—	.899	—	
	do	do	do	—	—	Aug. 1925	5.0	2,389,380	—	—	.846	—	
	do	do	do	—	—	Apr. 1935	9.7	2,270,300	—	*60	.475	621	
	do	do	do	—	—	Oct. 1940	5.5	2,219,000	—	—	.361	—	
	do	do	do	—	—	Apr. 1947	6.5	2,197,600	—	*65.9	.127	182	
	do	do	do	—	—	Feb. 1957	9.75	1/2,206,780	2.20	60.0	—	—	
	do	do	do	—	—	Apr. 1969	12.2	2,137,219	2.31	62	.22	357	
57-2	Caballo	do	Truth or Consequences, N. Mex.	2/30,700	3/1,237	Jan. 1938	—	345,872	—	—	—	—	BR
	do	do	do	—	—	Nov. 1957	19.9	343,990	—	—	.0761	—	
57-3a	Santa Cruz	Santa Cruz River	Espanola, N. Mex.	93.1	93.1	Feb. 1929	—	4,444	.190	—	—	—	SCS
	do	do	do	—	—	Aug. 1956	27.4	3,758	.160	80	.27	470	
57-4	Cornfield Wash (1)	Trib. of Rio Puerco River	Cuba, N. Mex.	.29	.28	Apr. 1951	—	24.0	1.446	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	10.3	.620	—	4.99	—	
57-5	Cornfield Wash (2)	do	do	.87	.85	Apr. 1951	—	54.1	3.127	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	45.1	2.607	—	1.06	—	
57-6	Cornfield Wash (3)	do	do	.25	.25	Apr. 1951	—	5.9	.711	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	2.6	.313	—	1.32	—	
57-7	Cornfield Wash (4)	do	do	1.18	1.17	Apr. 1951	—	22.1	1.277	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	17.4	1.006	—	.40	—	
57-8	Cornfield Wash (5)	do	do	1.04	1.04	Apr. 1951	—	9.2	.474	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	3.0	.155	—	.60	—	
57-9	Cornfield Wash (9)	do	do	.09	.09	Apr. 1951	—	4.6	.968	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	3.1	.639	—	1.67	—	
57-10	Cornfield Wash (13)	do	do	.33	.33	Apr. 1951	—	7.4	.561	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/10	.3	.023	—	2.15	—	
57-11	Cornfield Wash (15)	do	do	1.04	1.03	Dec. 1953	—	17.9	6.630	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/7	17.8	6.593	—	.01	—	
57-12	San Luis (1)	do	do	1.06	1.05	Aug. 1952	—	16.3	.676	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/8	12.0	.498	—	.51	—	
57-13	San Luis (3)	do	do	.67	.66	Aug. 1952	—	22.6	.958	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/8	19.6	.831	—	.58	—	
57-14	Zia Reservoir	Trib. of Jemez River	San Ysidro, N. Mex.	2.4	2.4	June 1954	—	59.9	2.155	—	—	—	GS
	do	do	do	—	—	Oct. 1960	4/7	19.0	.683	—	2.43	—	
57-15a	Jemez Canyon Reservoi	Jemez River	Bernalillo, N. Mex.	1,034	1,034	Oct. 1953	—	117,213	2.844	—	—	—	CE
	do	do	do	—	—	Jan. 1958	5/4.25	115,821	2.810	*75.7	.317	523	
	do	do	do	—	—	Aug. 1959	5/1.67	113,874	2.763	*75.7	1.128	1,860	
	do	do	do	—	—	Dec. 1965	5/6.33	112,809	2.737	*75.7	.162	267	
57-16	San Luis #2	Rio Puerco River	Cuba, N. Mex.	.74	.74	July 1952	—	*3.0	.120	—	—	—	FS
	do	do	do	—	—	July 1962	—	—	—	—	.62	—	
57-17	Caballo Arroyos Site 1 (Underwood).	Underwood Arroyo	Berry, N. Mex.	.87	.87	Nov. 1959	—	73.21	15.9	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	7.8	68.79	14.9	111	.64	1,547	
57-18	Site #6 (Alamo Arroyo)	Alamo Arroyo	Chimayo, N. Mex.	3.15	3.12	Apr. 1962	—	232	6.9	—	—	—	SCS
	do	do	do	—	—	Dec. 1968	6.7	160	4.76	*100	3.30	7,187	
57-19	Site #3 (Ramones Arroyo)	Ramones Arroyo	do	1.17	1.16	Sept. 1962	—	111	8.9	—	—	—	SCS
	do	do	do	—	—	Jan. 1969	6.3	69	5.5	*110	6.03	14,446	
	do	do	do	—	—	Oct. 1969	.7	37.5	3.0	*110	27.16	102,597	
57-20	North Salem Site #2	North Salem Arroyo	Salem, N. Mex.	3.8	3.8	Apr. 1957	—	204.71	*10.1	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	10.25	190.82	*9.4	98.5	.35	750.9	
57-21	Rodey (Hatch Valley Arroyo #5)	Rodey Arroyo	Hatch, N. Mex.	2.1	2.1	July 1958	—	170.91	15.4	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	9.1	141.25	12.7	85	1.55	2,869	
	UPPER PECOS RIVER BASIN												
58-1	Bonito	Bonito Creek, Kraut Gulch	Capitan, N. Mex.	40.0	39.9	June 1931	—	1,180	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1940	9	1,150	—	—	.083	—	
58-2a	Alamogordo	Pecos River	Ft. Sumner, N. Mex.	4,393	3,749	— 1936	—	156,750	.966	—	—	—	BR
	do	do	do	—	—	Sept. 1940	3.25	146,071	.881	*73.5	.876	1,410	
	do	do	do	—	—	Oct. 1943	3.08	130,280	.786	—	—	—	
	do	do	do	—	—	Apr. 1944	0.50	132,171	.797	*73.5	1.03	1,649	
	do	do	do	—	—	Sept. 1964	20.62	110,655	.668	*73.5	.281	450	
58-3a	Avalon (Lake Avalon)	Pecos River	Carlsbad, N. Mex.	16,030	1,080	Apr. 1907	—	7,600	—	—	—	—	BR
	do	do	do	—	—	Apr. 1941	34.00	6,633	—	—	6/.0263	—	
	do	do	do	—	—	July 1956	15.25	5,647	—	76.7	.0599	—	

58-4a	McMillan (Lake McMillan)	do	do	14,950	14,950	Jan.	1894	—	91,000	.344	—	—	—	BR
	do	do	do	—	—	June	1904	10.42	73,000	.276	—	.116	—	
	do	do	do	—	—	Nov.	1910	6.42	61,500	.232	—	.120	—	
	do	do	do	—	—	May	1915	4.50	45,500	.172	—	.238	—	
	do	do	do	—	—	June	1925	10.08	42,000	.159	—	.023	—	
	do	do	do	—	—	Dec.	1932	7.50	40,500	.153	—	.013	—	
	do	do	do	—	—	Jan.	1940	7.08	38,655	.146	*70	.017	—	
	do	do	do	—	—	July	1956	16.50	7/39,400	.149	8/62.4	.004	—	
58-5	Upper-Hondo Site #1	Salado Creek	Capitan, N. Mex.	122	93.92	May	1959	—	4,972.14	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1959	.42	4,946.54	—	*75	.65	1,060	
	do	do	do	—	—	May	1961	1.58	4,896.60	—	75	.34	555	
	do	do	do	—	—	Mar.	1962	.83	4,818.00	—	75	1.01	1,649	
	do	do	do	—	—	Feb.	1963	.92	4,796.41	—	75	.25	408	
	do	do	do	—	—	Jan.	1965	1.92	4,749.54	—	75	.26	424	
58-6	Bancroft #7	do	do	12	12	Feb.	1955	—	4.77	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.67	3.52	—	*75	.01	16	
58-7	Bancroft #9	do	do	.57	.57	Feb.	1955	—	7.20	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.67	1.59	—	*75	.92	1,500	
58-8	Bancroft #11	do	do	.69	.69	Feb.	1955	—	4.09	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.67	1.59	—	*75	.34	554	
58-9	Pearson #6	do	do	.19	.19	Mar.	1955	—	2.21	—	—	—	—	SCS
	do	do	do	—	—	May	1957	2.17	1.60	—	*75	1.46	2,380	
	do	do	do	—	—	Apr.	1959	1.91	1.52	—	*75	.24	391	
	do	do	do	—	—	Oct.	1965	6.50	.49	—	*75	.83	1,352	
58-10	Pearson #8	do	do	.24	.24	Mar.	1955	—	5.45	—	—	—	—	SCS
	do	do	do	—	—	Dec.	1956	1.75	4.30	—	*75	2.75	4,555	
	do	do	do	—	—	Jan.	1958	1.08	3.62	—	*75	2.63	4,280	
	do	do	do	—	—	Jan.	1959	1.00	3.02	—	*75	2.49	4,130	
	do	do	do	—	—	Oct.	1965	6.75	.55	—	*75	1.53	2,519	
58-11	Pearson #9	do	do	1.56	1.56	Nov.	1954	—	23.78	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.92	16.05	—	*75	.45	734	
58-12	Pearson #10	do	do	.71	.71	Mar.	1955	—	20.19	—	—	—	—	SCS
	do	do	do	—	—	May	1957	2.17	18.04	—	*75	1.39	2,262	
	do	do	do	—	—	Jan.	1958	.67	17.99	—	*75	.14	228	
	do	do	do	—	—	Oct.	1958	.75	17.58	—	*75	.76	1,241	
	do	do	do	—	—	Oct.	1965	7.00	16.05	—	*75	.31	505	
58-13	Pearson #18	do	do	1.80	1.80	Mar.	1955	—	15.60	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.67	2.20	—	*75	.70	1,142	
58-14	Pearson #20	do	do	9/.16	9/.16	Mar.	1955	—	6.55	—	—	—	—	SCS
	do	do	do	—	—	Oct.	1965	10.58	5.77	—	*75	.46	752	

COLORADO RIVER BASIN (BELOW HOOVER DAM)
Williams and Lower Gila River Basins

59-

GILA RIVER BASIN

60-1	Lake Pleasant	Agua Fria River	Phoenix, Ariz.	1,450	1,444	Apr.	1928	—	184,500	—	—	—	—	SCS
	do	do	do	—	—	Feb.	1941	12.9	176,456	—	—	.432	—	
60-2a	San Carlos (Coolidge Dam)	Gila River	Globe, Ariz.	12,900	*11,900	Nov.	1928	—	1,266,837	6.054	—	—	—	GS
	do	do	do	—	—	Feb.	1935	6.3	1,232,725	5.891	—	.455	—	
	do	do	do	—	—	Jan.	1937	1.9	1,230,695	5.882	—	.090	—	
	do	do	do	—	—	Jan.	1947	10.0	1,209,343	5.780	—	.179	—	
	do	do	do	—	—	—	1966	19.6	1,170,118	5.592	—	.168	—	
60-3	Stock Tank No. 16 (Bryce Dam)	Butler Wash	Eden, Ariz.	.69	.69	Mar.	1936	—	11.43	—	—	—	—	SCS
	do	do	do	—	—	—	1941	5.2	5.13	—	—	1.75	—	
60-4	Roosevelt-Salt River Project	Salt River & Tonto Creek	Globe, Ariz.	5,760	5,760	May	1909	—	1,522,200	1.886	—	—	—	BR
	do	do	do	—	—	Dec.	1914	5.7	1,495,460	1.853	*70	.819	1,248	
	do	do	do	—	—	Oct.	1916	1.8	1,460,150	1.809	*70	3.390	5,107	
	do	do	do	—	—	Sept.	1925	8.9	1,425,813	1.767	*70	.670	1,021	
	do	do	do	—	—	Jan.	1935	9.3	1,418,013	1.757	*70	.145	221	
	do	do	do	—	—	Jan.	1939	4.0	1,398,430	1.733	*70	.850	1,296	
	do	do	do	—	—	Jan.	1946	7.0	1,381,580	1.712	*70	.418	637	

1/ Total storage shows a gain of 9,180 ac.-ft. since 1947 survey attributable primarily to compaction.

2/ Includes 2,940 sq. mi. in closed basin in San Luis Valley, Colo.

3/ Drainage area between gaging station below Elephant Butte Dam and gaging station below Caballo Dam less original water surface area of Caballo Reservoir at elevation 4,225.3.

4/ Runoff seasons.

5/ Time periods adjusted.

6/ Compacted sediment for 1,080 sq. mi.; values for 16,030 sq. mi. are given in appendix summaries.

7/ Increase in capacity due mainly to compaction.

8/ Only surface samples (1.0-3.1 ft.) in approximately 1/3 of reservoir area below spillway crest.

9/ Drainage area is 100 ac. plus pipe flow from Pearson #11, which has a drainage area of 10 ac., plus pipe and emergency spillway flow from Pearson #18, which has a drainage area of 1.80 sq. mi.

* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
			GILA RIVER BASIN (Continued)										
60-5	Allen	Trib. of Gila River	Thatcher, Ariz.	1/4.17	4.13	— 1936	—	279	2.467	—	—	—	SCS
	do	do	do	—	—	June 1958	22	253	2.382	—	0.27	—	
60-6	"P" Mt. Tank No. 1	Whitewater Draw	Douglas, Ariz.	.21	.21	— 1917	—	2.94	.516	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	41	2.54	.446	*75	.05	81.7	
60-7	"P" Mt. No. 2	do	do	10.92	10.92	— 1938	—	2.55	.009	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	20	.70	.006	*75	.008	13.1	
60-8	"P" Mt. No. 3	do	do	2.48	2.48	Sept. 1947	—	14.7	.218	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	2/7	.0	0	*85	.85	1,573	
60-9	"P" Mt. No. 4	do	do	.36	.36	Mar. 1942	—	.43	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	2/12	.0	—	*90	.10	196	
60-10	"P" Mt. No. 5	do	do	12.3	12.3	— 1943	—	3.0	.009	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	3/5	2.7	.008	*75	.006	9.8	
60-11	"P" Mt. Pond No. 6	do	do	5.68	5.68	— 1941	—	.8	.005	—	—	—	SCS
	do	do	do	—	—	Nov. 1958	4/6	.6	.004	*75	.006	9.8	
60-12	Dos Cabezas No. 4 SW	Trib. of Willcox Dry Lake	Dos Cabezas, Ariz.	.6	.6	— 1949	—	6.0	.312	—	—	—	SCS
	do	do	do	—	—	Nov. 1960	11	4.1	.214	*90	.29	559	
60-13a	Dos Cabezas No. 15	do	do	.38	.38	— 1940	—	4.7	.385	—	—	—	SCS
	do	do	do	—	—	Oct. 1960	20	2.8	.230	*90	.26	510	
60-14	Belfrage	Trib. of Gila River	Florence, Ariz.	.2	.2	— 1941	—	6.8	1.089	—	—	—	SCS
	do	do	do	—	—	June 1960	19	3.9	1.083	*85	.75	1,388	
60-15	Homestead	do	do	.9	.9	— 1954	—	6.00	.368	—	—	—	SCS
	do	do	do	—	—	June 1960	6	1.83	.112	*90	.78	1,530	
60-16	Lower Foote Wash	Foote Wash	Safford, Ariz.	4.80	5/.63	— 1936	—	14.8	—	—	—	—	SCS
	do	do	do	—	—	June 1958	22	13.0	—	—	.13	—	
60-17	Magma No. 1	Magma Wash	Florence, Ariz.	1.78	1.78	— 1948	—	5.7	.176	—	—	—	SCS
	do	do	do	—	—	May 1959	11	2.7	.084	*80	.15	262	
60-18	Magma No. 2	do	do	.38	.38	Feb. 1954	—	1.6	.232	—	—	—	SCS
	do	do	do	—	—	May 1959	5.4	1.3	.188	*85	.15	278	
60-19a	Magma No. 3	do	do	21.9	*7.0	— 1949	—	6.0	—	—	—	—	SCS
	do	do	do	—	—	May 1959	10	3.8	—	*75	.03	49	
60-20	Riggs	Trib. Willcox Dry Lake	Dos Cabezas, Ariz.	.6	.6	— 1946	—	1.9	.099	—	—	—	SCS
	do	do	do	—	—	Oct. 1960	14	1.4	.073	*80	.06	105	
60-21	Upper Foote Wash	Foote Wash	Safford, Ariz.	4.95	4.95	— 1936	—	24.2	.209	—	—	—	SCS
	do	do	do	—	—	June 1958	22	19.5	.168	—	.04	—	
60-22	Whitlow Old Tank	Trib. of Gila River	Florence, Ariz.	.74	.74	— 1950	—	3.4	.754	—	—	—	SCS
	do	do	do	—	—	June 1960	10	1.8	.334	*85	.23	426	
60-23a	Bartlett	Verde	Sunflower, Ariz.	5,812	190	Feb. 1939	—	182,600	—	—	—	—	BR
	do	do	do	—	—	Aug. 1942	3.50	179,480	—	—	6/.156	—	
	do	do	do	—	—	Nov. 1950	8.33	2/179,548	—	—	—	—	
	do	do	do	—	—	Jan. 1964	13.17	178,480	—	—	.426	—	
60-24a	Horseshoe	do	do	5,618	5,614	Nov. 1945	—	67,900	.261	—	—	—	BR
	do	do	do	—	—	Oct. 1950	4.9	8/142,830	.507	—	.044	—	
	do	do	do	—	—	Nov. 1963	13.1	139,238	.496	—	.049	—	
60-25	Foote Wash Pond #3	Trib. of Foote Wash	Safford, Ariz.	.60	.58	— 1936*	—	19.10	*1.705	—	—	—	SCS
	do	do	do	—	—	Jan. 1964	*28	17.10	*1.527	76.2	.12	199	
60-26	Foote Wash Pond #4	Trib. of Gila River	do	.33	.33	— 1936*	—	6.462	*1.069	—	—	—	SCS
	do	do	do	—	—	Jan. 1964	*28	5.325	*.864	72.6	.12	190	
60-27	Williams-Chandler Pond #1	Trib. of Queen Creek	Florence Junction, Ariz.	1.09	1.09	— 1931	—	2.10	.197	—	—	—	SCS
	do	do	do	—	—	July 1961	30	1.00	.094	60	.033	43	
60-28	Williams-Chandler Pond #2	do	do	.65	.65	— 1944	—	9.33	1.346	—	—	—	SCS
	do	do	do	—	—	July 1961	17	8.95	1.291	60	.034	44	
60-29	Big Horn Mt. Tank #1	Trib. of Centennial Wash	Tonopah, Ariz.	.51	.51	June 1960	—	21.30	*7.83	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	4.3	21.06	*7.76	67.6	.11	116	
60-30	Big Horn Mt. Tank #2	do	do	.44	.44	July 1960	—	11.46	*4.88	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	4.3	11.26	*4.79	*50	.11	120	
60-31	Centennial Wash Tank	do	do	9/.60	9/.60	— 1954*	—	1.27	.397	—	—	—	SCS
	do	do	do	—	—	May 1965	*11	.67	.209	91.97	.09	180	
60-32	New Tank	do	do	9/1.88	9/1.88	— 1945	—	7.61	.759	—	—	—	SCS
	do	do	do	—	—	May 1965	20	4.08	.407	77.12	.096	158	
60-33	West Tank	do	Salome, Ariz.	.29	.29	June 1960	—	10.09	*6.51	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	4.3	9.93	*6.41	52.5	.13	148.7	
60-34	Upper Twin Tank	Tiger Wash	Aguila, Ariz.	1.83	1.83	Oct. 1944*	—	2.21	*.228	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	20	10/1.60	*.173	46	.015	15	
60-35	Harquahala Mt. Tank #1	Trib. of Brown's Canyon Wash	do	.11	.11	June 1958	—	6.64	*11.25	—	—	—	SCS
	do	do	do	—	—	Oct. 1964	6.3	6.50	*11.02	*50	.18	196	
60-36	Jedia Wash Retarding Dam	Jedia Wash	Solomon, Ariz.	4.60	4.57	Jan. 1957	—	158.79	*1.849	—	—	—	SCS
	do	do	do	—	—	Jan. 1964	7	154.24	*1.796	76.9	.14	234.5	
	do	do	do	—	—	July 1964	.6	153.16	*1.784	*76.9	.39	653.2	

60-37a	Three Bar B Debris Basin	Trib. of Rock Creek	Roosevelt, Ariz.	.073	.073	Aug.	1959	—	11/.23	.05	—	—	—	FS
	do	do	do	—	—	Oct.	1960	1.17	—	—	*110	12/18.77	12/44,969	
	do	do	do	—	—	Oct.	1961	1.00	—	—	*110	12/4.66	12/11,159	
	do	do	do	—	—	Oct.	1962	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1964	2.00	—	—	*110	12/.55	12/1,313	
	do	do	do	—	—	Oct.	1965	1.00	—	—	*110	12/.14	12/328	
	do	do	do	—	—	Oct.	1966	1.00	—	—	*110	12/.27	12/656	
	do	do	do	—	—	Oct.	1967	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1968	1.00	—	—	*110	12/.14	12/328	
	do	do	do	—	—	Oct.	1969	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1970	1.00	—	—	*110	0	0	
60-38a	Three Bar C Debris Basin	do	do	.149	.149	Aug.	1959	—	11/.08	.002	—	—	—	FS
	do	do	do	—	—	Oct.	1960	1.17	—	—	*110	12/5.57	12/13,345	
	do	do	do	—	—	Oct.	1961	1.00	—	—	*110	12/.67	12/1,608	
	do	do	do	—	—	Oct.	1962	1.00	—	—	*110	12/.67	12/1,608	
	do	do	do	—	—	Oct.	1964	2.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1965	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1966	1.00	—	—	*110	12/.34	12/804	
	do	do	do	—	—	Oct.	1967	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1968	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1969	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1970	1.00	—	—	*110	0	0	
60-39a	Three Bar D Debris Basin	do	do	.126	.126	Aug.	1959	—	11/.21	.01	—	—	—	FS
	do	do	do	—	—	Oct.	1960	1.17	—	—	*110	12/12.70	12/30,427	
	do	do	do	—	—	Oct.	1961	1.00	—	—	*110	12/3.73	12/8,937	
	do	do	do	—	—	Oct.	1962	1.00	—	—	*110	12/.63	12/1,521	
	do	do	do	—	—	Oct.	1964	2.00	—	—	*110	12/.04	12/95	
	do	do	do	—	—	Oct.	1965	1.00	—	—	*110	12/.08	12/190	
	do	do	do	—	—	Oct.	1966	1.00	—	—	*110	12/.08	12/190	
	do	do	do	—	—	Oct.	1967	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1968	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1969	1.00	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1970	1.00	—	—	*110	0	0	
60-40a	Three Bar F Debris Basin	do	do	.107	.107	Mar.	1963	—	11/.04	.004	—	—	—	FS
	do	do	do	—	—	Oct.	1963	.51	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1964	1.0	—	—	*110	12/.37	12/886	
	do	do	do	—	—	Oct.	1965	1.0	—	—	*110	12/.09	12/224	
	do	do	do	—	—	Oct.	1966	1.0	—	—	*110	12/.19	12/448	
	do	do	do	—	—	Oct.	1967	1.0	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1968	1.0	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1969	1.0	—	—	*110	0	0	
	do	do	do	—	—	Oct.	1970	1.0	—	—	*110	13/.08	13/2,016	
60-41	Bennett 14	Walnut Gulch	Tombstone, Ariz.	.6	.6	June	1961	—	18	.6	—	—	—	SCS
	do	do	do	—	—	June	1967	6	17	.6	75	.2	326	
60-42	Cowan 7	do	do	.4	.4	June	1963	—	14	1.7	—	—	—	SCS
	do	do	do	—	—	June	1967	4	13.5	1.7	75	.25	410	
60-43	Horsethief Basin	Horsethief Canyon	Crown King, Ariz.	.85	.85	—	1934	—	42.4	.44	—	—	—	FS
	do	do	do	—	—	Nov.	1969	36	35.6	.37	—	.22	—	
60-44	Lynx Lake	Lynx Creek	Prescott, Ariz.	18.14	*10	Nov.	1962	—	1,472	1.07	—	—	—	FS
	do	do	do	—	—	Nov.	1968	6	1,460	1.06	—	.197	—	
60-45	Granite Basin	Mint Wash	do	4.69	*4.69	—	1939	—	89	*.32	—	—	—	FS
	do	do	do	—	—	Aug.	1967	28	58	*.21	—	.236	—	
60-46	Keller Tank	Trib. Verde River	Scottsdale, Ariz.	.06	.06	Apr.	1941	—	—	—	—	—	—	SCS
	do	do	do	—	—	Aug.	1970	29.2	1,529	*1.91	—	.09	—	
60-47	Galleta Tank	Trib. Cent. Wash	Tonopah, Ariz.	.66	.665	June	1939	—	—	—	—	—	—	SCS
	do	do	do	—	—	Apr.	1967	27.9	21	6.63	74.8	.21	342	
60-48	Wellick Tank	Trib. Flying "E" Wash	Wickenburg, Ariz.	.79	.77	May	1956	—	79.1	20.87	—	—	—	SCS
	do	do	do	—	—	Sept.	1970	14.3	77.3	20.39	94.1	.16	328	
60-49	Pouquette Tank	Trib. Cemetery Wash	do	.13	.129	May	1965	—	.99	1.59	—	—	—	SCS
	do	do	do	—	—	Dec.	1970	5.6	.91	1.46	88.2	.10	192	

LITTLE COLORADO AND SAN JUAN RIVER BASINS

61-1	Oak Creek Reservoir	Trib. of Zuni River	Zuni, N. Mex.	9.41	9.41	Oct.	1954	—	334.8	1.425	—	—	—	GS
	do	do	do	—	—	May	1960	14/6	148.0	.630	—	3.32	—	

1/ Drainage area includes 1.87 sq. mi. diverted from Hawk Hollow.
2/ Reservoir was full of sediment in 1954.
3/ Constructed 1943, cleaned 1953.
4/ Constructed 1941, cleaned 1952.
5/ This reservoir is downstream from Upper Foote Wash Reservoir. Little or no sediment is contributed from the 4.17 sq. mi. above this dam.
6/ Based on total drainage area of 5,812 sq. mi. before construction of Horseshoe Dam upstream.
7/ Increase in capacity probably due to compaction.
8/ Capacity increased 76,130 ac.-ft. by installation of spillway gates in June 1950.
9/ Drainage area is smallest area that could be positively delineated.
10/ Storage capacity at original spillway crest elevation - storage capacity at eroded spillway elevation 0.53 ac.-ft.
11/ Basin cleaned as needed to maintain capacity.
12/ Includes sediment trapped above spillway level.
13/ Basin filled during storm of 9-5-70 and undetermined amount of sediment escapes from pond.
14/ Runoff seasons.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	LITTLE COLORADO AND SAN JUAN RIVER BASINS (Continued)												
61-2a	Willet Swale Reservoir	Trib. of Silver Creek	Taylor, Ariz.	40.0	39.7	June 1959	—	1,342.0	2.1	—	—	—	SCS
	do	do	do	—	—	June 1962	3	1,259.4	2.0	67	0.69	1,007	
	do	do	do	—	—	June 1966	4	1,118.5	1.7	80	.89	1,551	
61-3	Stockyard Tank	Trib. Cottonwood Wash	Snowflake, Ariz.	.48	.476	— 1943	—	6.04	*.79	—	—	—	SCS
	do	do	do	—	—	May 1968	25	4.02	*.52	101.6	.17	376	
61-4	Thomas Tank I	do	do	.55	.549	— 1947	—	3.09	*.35	—	—	—	SCS
	do	do	do	—	—	June 1968	21	1.38	*.16	77.9	.15	250	
61-5	Ellsworth Tank	Trib. Show Low Creek	Taylor, Ariz.	.25	.249	— 1948	—	1.90	*.23	—	—	—	SCS
	do	do	do	—	—	Aug. 1968	20	1.27	*.19	80	.044	79	
61-6	New Tank	Trib. Cottonwood Wash	Snowflake, Ariz.	2.45	2.45	— 1938	—	10.13	*.15	—	—	—	SCS
	do	do	do	—	—	May 1968	30	9.10	*.14	87.7	.014	27	
61-7	West Hall Tank	do	Clay Springs, Ariz.	.32	.32	— 1944	—	.76	*.09	—	—	—	SCS
	do	do	do	—	—	June 1968	24	.61	*.07	93.4	.02	41	
61-8	Thomas Tank II	Trib. Perkins Spring Draw	do	.10	.10	June 1964	—	1.39	*.52	—	—	—	SCS
	do	do	do	—	—	July 1968	4	1.35	*.50	89.3	.10	196	
	COLORADO RIVER BASIN (HALLS CROSSING TO HOOVER DAM)												
62-1	Lake Mead (Hoover Dam)	Colorado River	Boulder City, Nev.	167,800	1/167,600	Feb. 1935	—	31,250,000	2.140	—	—	—	GS
	do	do	do	—	—	Sept. 1948 2/	13.7	29,827,000	2.043	3/65	.620	877	
62-2	Brooksby Tank	Trib. of Johnson Wash	Fredonia, Ariz.	.4	.4	— 1951	—	.697	.327	—	—	—	SCS
	do	do	do	—	—	Sept. 1965	4/14	.140	.066	97	4/.10	211	
62-3	Riggs Flat Charco	Sandy Canyon Wash	do	57.86	57.83	Oct. 1956	—	56.93	.178	—	—	—	SCS
	do	do	do	—	—	Sept. 1965	8.9	36.58	.119	72	.035	55	
62-4	Leroy Judd Tank	Trib. of Kanab Creek	do	.38	.38	— 1962	—	.95	.468	—	—	—	SCS
	do	do	do	—	—	Aug. 1965	3	.22	.108	105.7	.63	1,450	
62-5	Kaibab Indian Reservation Erosion Control Structure.	do	Indian Moccasin, Ariz.	1.27	1.27	— 1935	—	6.008	.887	—	—	—	SCS
	do	do	do	—	—	Oct. 1965	30	2.267	.332	87.2	.098	186	
62-6	Jesse Judd Tank	do	Fredonia, Ariz.	5/3.49	5/3.49	— 1955	—	7.10	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1965	6/10	2.77	—	*80	6/.12	209	
62-7	Frog Hollow Detention Res.	Frog Hollow Wash	Hurricane, Utah	9.2	9.2	Jan. 1957	—	223.0	*1.517	—	—	—	SCS
	do	do	do	—	—	Jan. 1958	*1	216.4	*1.472	*80	.72	1,255	
	do	do	do	—	—	Nov. 1965	7.8	160.8	*.958	*80	1.05	1,830	
62-8	CCC Pond (West)	Trib. Santa Clara River	St. George, Utah	.03	.03	— 1941	—	—	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1966	25	*.2	*.63	92	7/.23	461	
62-9	CCC Pond (East)	do	do	.32	.32	— 1941	—	—	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1966	25	*.2	*.06	90	7/.037	33	
62-10	Rondo Russch Debris Basin #2	Trib. Virgin River	do	.026	.026	— 1944	—	—	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1966	22	*1.5	*5.3	*90	7/3.35	6,566	
62-11	Rondo Russch Debris Basin #1	do	do	.09	.09	— 1944	—	—	—	—	—	—	SCS
	do	do	do	—	—	Feb. 1966	22	*1.0	*1.0	*90	7/.61	1,196	
62-12	Iliff Andrus	Trib. Warner Draw	do	1.09	1.08	— 1949	—	—	—	—	—	—	SCS
	do	do	do	—	—	Jan. 1966	17	*20	*2.2	78	7/.76	1,290	
62-13	Winfred Spendlove	Trib. Fort Pearce Wash	do	.85	.84	— 1946	—	—	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1966	20	*7.0	*1.1	87.5	7/.42	800	
62-14	Black Knolls	Trib. City Creek	do	.59	.58	— 1922	—	—	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1965	43	*20	*3.2	*75	.34	555	
62-15	Little Grassy Pond	Unknown	do	2.3	2.3	— 1943	—	—	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1966	23	*2.0	—	96	7/.043	88	
62-16	Bill Shaw Pond	Trib. Santa Clara River	do	.057	.057	— 1956	—	—	—	—	—	—	SCS
	do	do	do	—	—	June 1966	10	*2.0	*3.3	72	7/1.79	2,820	
62-17	Manganese Wash	Manganese Wash	do	.17	.17	— 1956	—	—	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1966	10	*1.0	*.2	80	7/.38	662	
	COLORADO RIVER BASIN (ABOVE HALLS CROSSING) Gunnison, Dolores and Fremont River Basins												
63-1	Badger Detention (1A)	Badger Wash	Mack, Colo.	1.53	1.49	May 1957	—	201.52	3.336	—	—	—	GS
	do	do	do	—	—	Nov. 1958	1.6	199.35	3.300	—	.92	—	
	do	do	do	—	—	Nov. 1959	1.0	196.27	3.250	—	2.07	—	
	do	do	do	—	—	Nov. 1961	2.0	190.38	3.152	—	1.97	—	

63-2	Badger Wash West Twin (2A)	-do-	-do-	.167	.165	Dec.	1953	—	6.30	.957	—	—	—	08
	-do-	-do-	-do-	—	—	July	1955	1.6	4.47	.679	—	6.91	—	
	-do-	-do-	-do-	—	—	Nov.	1956	1.4	4.47	.679	—	0	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	3.98	.605	—	2.97	—	
	-do-	-do-	-do-	—	—	Nov.	1958	1.0	3.98	.605	—	0	—	
	-do-	-do-	-do-	—	—	Nov.	1959	1.0	3.65	.555	—	2.00	—	
	-do-	-do-	-do-	—	—	Nov.	1961	2.0	2.43	.369	—	3.70	—	
63-3	Badger Wash Lower Oil Well (3A)	-do-	-do-	.059	.055	Dec.	1953	—	12.90	4.813	—	—	—	08
	-do-	-do-	-do-	—	—	July	1955	1.6	12.65	4.720	—	2.91	—	
	-do-	-do-	-do-	—	—	Nov.	1956	1.4	12.65	4.720	—	0	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	12.55	4.683	—	1.82	—	
	-do-	-do-	-do-	—	—	Nov.	1958	1.0	12.55	4.683	—	0	—	
	-do-	-do-	-do-	—	—	Nov.	1959	1.0	12.33	4.601	—	4.00	—	
	-do-	-do-	-do-	—	—	Nov.	1961	2.0	12.12	4.522	—	1.82	—	
63-4	East Basin (11)	-do-	-do-	.089	.087	Apr.	1954	—	5.45	1.135	—	—	—	08
	-do-	-do-	-do-	—	—	Nov.	1956	2.6	4.92	1.025	—	2.30	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	4.76	.992	—	1.84	—	
	-do-	-do-	-do-	—	—	Nov.	1959	2.0	4.65	.969	—	.69	—	
63-5	Middle Basin (12)	-do-	-do-	.092	.088	Apr.	1954	—	16.93	2.996	—	—	—	08
	-do-	-do-	-do-	—	—	Nov.	1956	2.6	15.87	2.809	—	4.66	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	15.38	2.722	—	5.57	--	
	-do-	-do-	-do-	—	—	Nov.	1959	2.0	15.32	2.712	—	.34	—	
63-6a	Prairie Dog (4A)	Trib. Badger Wash	-do-	.022	.022	Dec.	1953	—	3.05	4.36	—	—	—	08
	-do-	-do-	-do-	—	—	July	1955	1.6	2.64	3.77	*90	11.8	23,130	
	-do-	-do-	-do-	—	—	Nov.	1956	1.3	2.64	3.77	*90	0	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	2.49	3.56	*90	6.82	13,365	
	-do-	-do-	-do-	—	—	Nov.	1958	1.1	2.49	3.56	*90	0	--	
	-do-	-do-	-do-	—	—	Nov.	1959	1.0	2.43	3.47	*90	2.73	5,346	
	-do-	-do-	-do-	—	—	Nov.	1961	2.0	2.28	3.26	*90	3.18	6,682	
	-do-	-do-	-do-	—	—	Nov.	1963	2.0	2.17	3.10	*90	2.27	4,900	
	-do-	-do-	-do-	—	—	Nov.	1964	1.0	2.03	2.90	*90	6.36	12,476	
	-do-	-do-	-do-	—	—	Nov.	1965	1.0	1.82	2.60	*90	9.55	18,711	
	-do-	-do-	-do-	—	—	Nov.	1966	1.0	1.91	2.73	*90	—	—	
	-do-	-do-	-do-	—	—	Oct.	1967	1.0	1.80	2.57	*90	5.50	9,802	
	-do-	-do-	-do-	—	—	Nov.	1968	1.0	1.66	2.37	*90	6.36	10,496	
	-do-	-do-	-do-	—	—	June	1970	1.6	8/2.52	3.60	*90	0	--	
	-do-	-do-	-do-	—	—	Oct.	1970	.4	2.50	3.57	*90	2.27	4,455	
63-7	Southeast (13)	Badger Wash	-do-	.484	.477	Apr.	1954	—	27.25	1.854	—	—	—	08
	-do-	-do-	-do-	—	—	Nov.	1956	2.6	24.85	1.690	—	1.93	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	23.44	1.595	—	2.96	—	
	-do-	-do-	-do-	—	—	Nov.	1999	2.0	22.26	1.514	—	1.24	—	
63-8a	Upper Banks (1A)	Trib. Badger Wash	-do-	.066	.066	Dec.	1953	—	8.30	3.81	—	—	—	08
	-do-	-do-	-do-	—	—	July	1955	1.6	7.59	3.48	*90	6.60	13,096	
	-do-	-do-	-do-	—	—	Nov.	1956	1.3	7.59	2.56	*90	0	—	
	-do-	-do-	-do-	—	—	Nov.	1957	1.0	7.34	3.37	*90	3.78	7,425	
	-do-	-do-	-do-	—	—	Nov.	1958	1.1	7.34	3.37	*90	0	—	
	-do-	-do-	-do-	—	—	Nov.	1959	1.0	7.04	3.23	*90	4.55	9,061	
	-do-	-do-	-do-	—	—	Nov.	1961	2.0	6.70	3.07	*90	2.73	5,198	
	-do-	-do-	-do-	—	—	Nov.	1963	2.0	6.59	3.02	*90	.83	1,634	
	-do-	-do-	-do-	—	—	Nov.	1964	1.0	6.55	3.00	*90	.60	1,188	
	-do-	-do-	-do-	—	—	Nov.	1965	1.0	6.10	2.84	*90	6.82	13,365	
	-do-	-do-	-do-	—	—	Nov.	1966	1.0	6.16	2.82	*90	9/—	—	
	-do-	-do-	-do-	—	—	Oct.	1967	1.0	6.00	2.75	*90	2.41	4,752	
	-do-	-do-	-do-	—	—	Nov.	1968	1.0	5.48	2.51	*90	7.84	15,444	
	-do-	-do-	-do-	—	—	Nov.	1969	1.0	5.54	2.54	*90	9/—	—	
63-9	West Twin (2-A)	-do-	-do-	.148	.148	Dec.	1953	—	6.30	1.31	—	—	—	08
	-do-	-do-	-do-	—	—	July	1955	1.6	4.38	.91	*90	8.10	15,878	
	-do-	-do-	-do-	—	—	Nov.	1956	1.3	4.38	.91	*90	0	—	
	-do-	-do-	-do-	—	—	Oct.	1957	1.0	3.90	.81	*90	3.24	6,357	
	-do-	-do-	-do-	—	—	Nov.	1958	1.1	3.90	.81	*90	0	—	
	-do-	-do-	-do-	—	—	Nov.	1959	1.0	10/15.08	3.13	*90	1.49	2,914	
	-do-	-do-	-do-	—	—	Nov.	1961	2.0	13.86	2.88	*90	4.12	8,079	
	-do-	-do-	-do-	—	—	Nov.	1963	2.0	13.52	2.80	*90	1.15	2,252	
	-do-	-do-	-do-	—	—	Nov.	1964	1.0	12.39	2.57	*90	7.64	14,966	
	-do-	-do-	-do-	—	—	Nov.	1965	1.0	12.06	2.50	*90	2.23	4,371	
	-do-	-do-	-do-	—	—	Nov.	1966	1.0	12.10	2.51	*90	9/—	—	
	-do-	-do-	-do-	—	—	Oct.	1967	1.0	11.53	2.39	*90	3.85	7,549	
	-do-	-do-	-do-	—	—	Nov.	1968	1.0	10.56	2.09	*90	6.55	12,847	
	-do-	-do-	-do-	—	—	Nov.	1969	1.0	10.64	2.10	*90	9/—	—	

1/ Not adjusted for numerous small reservoirs. Runoff used to compute C/I ratio was not adjusted for upstream diversion.

2/ Period of survey was from Mar. 1948 - Mar. 1949.

3/ Based on measured and estimated sediment inflow of 2,000,000,000 tons in 13.7 yr. period.

4/ Estimated effective life of pond is 5 yr. 1951 - 1956.

5/ Reservoir is off main channel. Estimate reservoir intercepts 1/3 of flow and sediment from total drainage area.

6/ Effective life of reservoir is estimated at 8 yr. storm in 1963 filled reservoir and changed channel course.

7/ Includes deposition above spillway crest level.

8/ Reservoir cleaned in June 1970.

9/ Capacity increase.

10/ Dam and spillway raised in 1959.

* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	COLORADO RIVER BASIN (ABOVE HALLS CROSSING) Gunnison, Dolores and Fremont River Basins (Continued)												
63-10	Oil Well (3-A)	Trib. of Badger Wash	Mack, Colo.	0.059	0.059	Dec. 1953	—	12.92	5.71	—	—	—	GS
	do	do	do	—	—	July 1955	1.6	12.18	5.39	*90	7.80	15,289	
	do	do	do	—	—	Nov. 1956	1.3	12.18	5.39	*90	0	—	
	do	do	do	—	—	Oct. 1957	1.0	11.90	5.26	*90	4.75	9,302	
	do	do	do	—	—	Nov. 1958	1.1	11.90	5.26	*90	0	—	
	do	do	do	—	—	Nov. 1959	1.0	11.64	5.15	*90	4.40	8,638	
	do	do	do	—	—	Nov. 1961	2.0	11.31	5.00	*90	2.71	5,482	
	do	do	do	—	—	Nov. 1963	2.0	11.25	4.98	*90	.51	997	
	do	do	do	—	—	Nov. 1964	1.0	11.21	4.96	*90	.68	1,329	
	do	do	do	—	—	Nov. 1965	1.0	10.73	4.75	*90	8.14	15,947	
	do	do	do	—	—	Nov. 1966	1.0	10.82	4.79	*90	1/--	—	
	do	do	do	—	—	Oct. 1967	1.0	10.62	4.70	*90	3.39	6,645	
	do	do	do	—	—	Nov. 1968	1.0	10.15	4.49	*90	7.96	15,615	
	do	do	do	—	—	Nov. 1969	1.0	10.13	4.48	*90	.34	664	
	do	do	do	—	—	Oct. 1970	1.0	9.99	4.42	*90	2.38	4,651	
63-11	Windy Point (4-B)	do	do	.019	.019	Dec. 1953	—	4.52	9.62	—	--	—	GS
	do	do	do	—	—	July 1955	1.6	4.31	9.17	*90	6.85	13,427	
	do	do	do	—	—	Nov. 1956	1.3	4.31	9.17	*90	0	—	
	do	do	do	—	—	Oct. 1957	1.0	4.19	8.91	*90	6.32	12,380	
	do	do	do	—	—	Nov. 1958	1.1	4.19	8.91	*90	0	—	
	do	do	do	—	—	Nov. 1959	1.0	4.16	8.85	*90	1.58	3,095	
	do	do	do	—	—	Nov. 1961	2.0	4.14	8.80	*90	.53	1,032	
	do	do	do	—	—	Nov. 1963	2.0	4.12	8.76	*90	.53	1,032	
	do	do	do	—	—	Nov. 1964	1.0	4.03	8.57	*90	4.74	9,285	
	do	do	do	—	—	Nov. 1965	1.0	3.89	8.28	*90	7.37	14,443	
	do	do	do	—	—	Nov. 1966	1.0	3.89	8.28	*90	0	—	
	do	do	do	—	—	Oct. 1967	1.0	3.81	8.11	*90	4.21	8,253	
	do	do	do	—	—	Nov. 1968	1.0	3.74	7.96	*90	3.68	7,222	
	do	do	do	—	—	Nov. 1969	1.0	3.83	8.15	*90	1/—	—	
63-12	Tenca (2-B)	do	do	.158	.158	Dec. 1953	—	8.45	2.14	—	—	—	GS
	do	do	do	—	—	July 1955	1.6	6.05	1.53	*90	9.50	18,622	
	do	do	do	—	—	Nov. 1956	1.3	6.05	1.53	*90	0	—	
	do	do	do	—	—	Oct. 1957	1.0	5.94	1.50	*90	.70	1,365	
	do	do	do	—	—	Nov. 1958	1.1	5.94	1.50	*90	0	—	
	do	do	do	—	—	Nov. 1959	1.0	2/24.80	6.28	*90	2.15	2,840	
	do	do	do	—	—	Nov. 1961	2.0	24.18	6.12	*90	1.96	3,846	
	do	do	do	—	—	Nov. 1963	2.0	23.89	6.05	*90	.95	1,110	
	do	do	do	—	—	Nov. 1964	1.0	23.45	5.94	*90	2.78	5,459	
	do	do	do	—	—	Nov. 1965	1.0	23.15	5.86	*90	1.90	3,722	
	do	do	do	—	—	Nov. 1966	1.0	23.23	5.88	*90	1/—	—	
	do	do	do	—	—	Oct. 1967	1.0	22.86	5.79	*90	2.34	4,590	
	do	do	do	—	—	Nov. 1968	1.0	21.88	5.54	*90	6.20	12,158	
	do	do	do	—	—	Nov. 1969	1.0	22.12	5.60	*90	1/--	—	
63-13	North Basin (3-B)	do	do	.048	.048	Dec. 1953	--	8.10	4.60	--	—	—	GS
	do	do	do	—	—	July 1955	1.6	7.69	4.37	*90	5.42	10,624	
	do	do	do	—	--	Nov. 1956	1.3	7.69	4.37	*90	0	—	
	do	do	do	—	--	Oct. 1957	1.0	7.58	4.31	*90	2.29	4,492	
	do	do	do	—	—	Nov. 1958	1.1	7.58	4.31	*90	0	—	
	do	do	do	—	—	Nov. 1959	1.0	7.51	4.27	*90	1.46	2,859	
	do	do	do	—	—	Nov. 1961	2.0	7.38	4.19	*90	1.46	2,654	
	do	do	do	—	—	Nov. 1963	2.0	7.10	4.03	*90	2.92	5,717	
	do	do	do	—	—	Nov. 1964	1.0	7.05	4.00	*90	1.04	2,042	
	do	do	do	—	—	Nov. 1965	1.0	6.81	3.87	*90	5.00	9,801	
	do	do	do	—	—	Nov. 1966	1.0	6.81	3.87	*90	0	--	
	do	do	do	—	—	Oct. 1967	1.0	6.54	3.72	*90	5.63	11,026	
	do	do	do	—	—	Nov. 1968	1.0	6.07	3.45	*90	9.80	19,194	
	do	do	do	—	—	Nov. 1969	1.0	6.18	3.51	*90	1/--	--	
	do	do	do	—	—	Oct. 1970	1.0	6.13	3.48	*90	1.04	2,042	

63-14	Lower Hunks (1-8)	do	do	.084	.084	Dec. 1953	—	19.80	8.69	—	—	—	CS
	do	do	do	—	—	July 1955	1.6	19.17	8.41	*90	4.65	9,095	
	do	do	do	—	—	Nov. 1956	1.3	19.17	8.41	*90	0	0	
	do	do	do	—	—	Oct. 1957	1.0	19.17	8.41	*90	0	0	
	do	do	do	—	—	Nov. 1958	1.1	19.17	8.41	*90	0	0	
	do	do	do	—	—	Nov. 1959	1.0	19.17	8.41	*90	0	0	
	do	do	do	—	—	Nov. 1961	2.0	18.85	8.27	*90	1.90	3,734	
	do	do	do	—	—	Nov. 1963	2.0	18.74	8.22	*90	.99	1,283	
	do	do	do	—	—	Nov. 1964	1.0	18.72	8.21	*90	.24	467	
	do	do	do	—	—	Nov. 1965	1.0	18.38	8.06	*90	4.05	7,934	
	do	do	do	—	—	Nov. 1966	1.0	18.42	8.08	*90	1/ —	—	
	do	do	do	—	—	Oct. 1967	1.0	18.25	8.00	*90	2.02	3,967	
	do	do	do	—	—	Nov. 1968	1.0	17.63	7.73	*90	7.38	14,468	
	do	do	do	—	—	Nov. 1969	1.0	17.60	7.72	*90	.36	700	
63-15	Bone Mountain No.1	Trib. Alkali Creek	Walcott, Colo.	.0116	.011	July 1965	—	1.877	—	--	—	—	CS
	do	do	do	—	—	Nov. 1965	.30	1.851	2.64	*90	7.91	15,900	
	do	do	do	—	—	Oct. 1966	1.0	1.860	2.66	*90	1/ —	—	
	do	do	do	—	—	Nov. 1967	1.0	1.852	2.65	*90	.73	1,420	
	do	do	do	—	—	Nov. 1968	1.0	1.842	2.63	*90	.91	1,780	
	do	do	do	—	—	Nov. 1969	1.0	1.841	2.63	*90	.09	178	
	do	do	do	—	—	Nov. 1970	1.0	1.837	2.62	*90	.36	710	
63-16	Bone Mountain No. 3	do	do	.008	.008	July 1965	—	1.686	3.24	--	—	—	CS
	do	do	do	—	—	Nov. 1965	.28	1.644	3.16	*90	18.8	36,850	
	do	do	do	--	—	Oct. 1966	1.0	1.651	3.18	*90	1/ —	—	
	do	do	do	—	—	Nov. 1967	1.0	1.634	3.14	*90	2.13	4,165	
	do	do	do	—	—	Nov. 1968	1.0	1.637	3.15	*90	1/ —	--	
	do	do	do	—	—	Nov. 1969	1.0	1.619	3.11	*90	2.25	4,410	
	do	do	do	—	—	Nov. 1970	1.0	1.613	3.10	*90	.75	1,470	
63-17	Fool Creek Debris Basin	Fool Creek	Fraser, Colo.	1.11	1.11	Oct. 1951	--	—	—	--	—	—	FS
	do	do	do	—	—	Oct. 1952	1.0	—	—	—	.032	65.28	
	do	do	do	—	—	Oct. 1953	1.0	—	—	—	.016	32.64	
	do	do	do	—	—	Oct. 1954	1.0	—	--	—	—	0	
	do	do	do	—	—	Oct. 1955	1.0	—	—	—	—	0	
	do	do	do	—	—	Oct. 1956	1.0	—	—	—	.026	53.12	
	do	do	do	—	—	Oct. 1957	1.0	—	—	—	.051	101.76	
	do	do	do	—	—	Oct. 1958	1.0	—	—	—	.031	62.08	
	do	do	do	—	—	Oct. 1959	1.0	—	—	—	.006	12.48	
	do	do	do	—	—	Oct. 1960	1.0	—	—	—	.010	20.16	
	do	do	do	—	—	Oct. 1961	1.0	—	—	—	.004	8.96	
	do	do	do	—	—	Oct. 1962	1.0	—	—	—	.012	23.68	
	do	do	do	—	—	Oct. 1963	1.0	—	—	—	—	0	
	do	do	do	—	—	Oct. 1964	1.0	—	—	—	—	0	
	do	do	do	—	—	Oct. 1965	1.0	—	—	—	.018	36.16	
	do	do	do	—	—	Oct. 1966	1.0	—	—	—	.004	8.0	
	do	do	do	—	—	Oct. 1967	1.0	—	—	—	.005	10.32	
	do	do	do	—	—	Oct. 1968	1.0	—	—	—	.008	17.96	
	do	do	do	—	—	Oct. 1969	1.0	—	—	—	.010	22.45	
	do	do	do	—	—	Oct. 1970	1.0	—	—	—	.011	24.66	
63-18	Deadhorse Weir	Deadhorse Creek	do	1.04	1.04	Oct. 1954	—	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1955	1.0	—	—	—	.003	6.4	
	do	do	do	—	—	Oct. 1956	1.0	—	—	—	.012	26.88	
	do	do	do	—	—	Oct. 1957	1.0	—	—	—	.016	35.52	
	do	do	do	—	—	Oct. 1958	1.0	—	—	—	.006	3.2	
	do	do	do	—	—	Oct. 1959	1.0	—	—	—	.004	7.68	
	do	do	do	—	—	Oct. 1960	1.0	—	—	—	.004	7.68	
	do	do	do	—	—	Oct. 1961	1.0	—	—	—	.001	1.60	
	do	do	do	—	—	Oct. 1962	1.0	—	—	—	.009	19.84	
	do	do	do	—	—	Oct. 1963	1.0	—	--	—	.001	1.28	
	do	do	do	—	—	Oct. 1964	1.0	—	—	—	.001	2.24	
	do	do	do	—	—	Oct. 1965	1.0	—	—	—	.005	11.20	
	do	do	do	—	—	Oct. 1966	1.0	—	—	—	.001	1.28	
	do	do	do	—	—	Oct. 1967	1.0	—	—	—	.0004	.83	
	do	do	do	—	—	Oct. 1968	1.0	—	—	—	.001	1.81	
	do	do	do	—	—	Oct. 1969	1.0	—	—	—	.002	3.46	
	do	do	do	—	—	Oct. 1970	1.0	—	—	—	.005	10.71	

1/ Capacity increase.
2/ Dam and spillway raised in 1959.

* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
COLORADO RIVER BASIN (ABOVE HALLS CROSSING) Gunnison, Dolores and Fremont River Basins (Continued)													
63-19	Lexen Creek Weir	Lexen Creek	Fraser, Colo.	0.48	0.48	Oct. 1955	—	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1956	1.0	—	—	—	0.005	10.24	
	do	do	do	—	—	Oct. 1957	1.0	—	—	—	.009	17.92	
	do	do	do	—	—	Oct. 1958	1.0	—	—	—	.011	21.12	
	do	do	do	—	—	Oct. 1959	1.0	—	—	—	.002	3.84	
	do	do	do	—	—	Oct. 1960	1.0	—	—	—	.002	3.52	
	do	do	do	—	—	Oct. 1961	1.0	—	—	—	.0003	.64	
	do	do	do	—	—	Oct. 1962	1.0	—	—	—	.005	8.96	
	do	do	do	—	—	Oct. 1963	1.0	—	—	—	.0002	.32	
	do	do	do	—	—	Oct. 1964	1.0	—	—	—	.002	2.88	
	do	do	do	—	—	Oct. 1965	1.0	—	—	—	.003	5.76	
	do	do	do	—	—	Oct. 1966	1.0	—	—	—	.002	2.24	
	do	do	do	—	—	Oct. 1967	1.0	—	—	—	.001	1.73	
	do	do	do	—	—	Oct. 1968	1.0	—	—	—	.001	1.50	
	do	do	do	—	—	Oct. 1969	1.0	—	—	—	.001	1.50	
	do	do	do	—	—	Oct. 1970	1.0	—	—	—	.002	4.00	
63-20	East St. Louis Creek Weir	East St. Louis Creek	do	3.10	3.10	Oct. 1964	1.0	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1965	1.0	—	—	*100	.002	5.45	
	do	do	do	—	—	Oct. 1966	1.0	—	—	*100	.001	1.35	
	do	do	do	—	—	Oct. 1967	1.0	—	—	*100	.002	3.40	
	do	do	do	—	—	Oct. 1968	1.0	—	—	*100	.002	4.20	
	do	do	do	—	—	Oct. 1969	1.0	—	—	*100	.001	2.90	
	do	do	do	—	—	Oct. 1970	1.0	—	—	*100	.002	4.25	
63-21	RW-1 Roatcap Wash Watershed	Roatcap Wash	Olathe, Colo.	11.6	11.5	Dec. 1964	—	829.6	*7.0	—	—	—	SCS
	do	do	do	—	—	Nov. 1970	6	810.0	*6.9	—	.28	—	
GREEN RIVER BASIN													
64-1	Duck Fork	Ferron Creek	Ferron, Utah	3.56	3.56	— 1942	—	718	*.236	—	—	—	SCS
	do	do	do	—	—	Oct. 1962	20	1/870	*.286	*60	.14	183	
64-2	South Soda Creek Weir	South Soda Creek	Steamboat Springs, Colo.	3.40	3.40	Oct. 1967	—	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1968	1.0	—	—	*135	.005	13.43	
	do	do	do	—	—	Oct. 1969	1.0	—	—	*135	.0003	1.08	
	do	do	do	—	—	Oct. 1970	1.0	—	—	*135	.005	14.92	
64-3	North Fish Creek Weir	North Fish Creek	do	2.24	—	Oct. 1968	—	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1969	1.0	—	—	*135	.001	1.62	
	do	do	do	—	—	Oct. 1970	1.0	—	—	*135	.004	11.74	
64-4	West Walton Creek Weir	Trib. Walton Creek	do	1.33	1.33	Oct. 1967	—	—	—	—	—	—	FS
	do	do	do	—	—	Oct. 1968	1.0	—	—	*110	.016	38.28	
	do	do	do	—	—	Oct. 1969	1.0	—	—	*110	.006	15.07	
	do	do	do	—	—	Oct. 1970	1.0	—	—	*110	.020	47.90	
64-5	Bullwinkle	Trib. Brush Creek	Vernal, Utah	.11	.11	— 1938	—	—	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1968	30	*5.0	—	*70	2/.79	1,204	
64-6	Rock Canyon	Rock Canyon	do	1.41	1.41	— 1936	—	—	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1968	22	*5.0	—	*60	.011	14	
64-7	Miles Haslem Pond	Trib. Steinaker Draw	do	.095	.095	— 1952	—	—	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1967	15	*2.0	—	*70	2/.67	1,021	
64-8	Masser Reservoir	Trib. Twelve Mile Wash	do	.65	.65	— 1942	—	—	—	—	—	—	SCS
	do	do	do	—	—	May 1968	26	*8.0	—	*90	2/.23	450	
GREAT SALT LAKE BASIN													
65-1	East Canyon	East Canyon Creek	Morgan, Utah	144	144	— 1896	—	3/3,850	.098	—	—	—	BR
	do	do	do	—	—	Oct. 1954	58	28,730	.733	4/77.1	.124	208	
65-2	Echo	Weber River	Echo, Utah	732	732	Oct. 1930	—	75,718	.373	—	—	—	BR
	do	do	do	—	—	Oct. 1954	24	73,900	.364	4/71	.104	161	
65-3a	Santaquin Debris Basin	Summit Creek	Santaquin, Utah	17.65	13.5	Fall 1954	—	*84	.008	—	—	—	SCS
	do	do	do	—	—	Dec. 1957	3	*65	.006	*90	.47	921	
SEVIER RIVER BASIN													
66-1	Booby Hole	Booby Hole Creek	Koosharem, Utah	5.0	4.9	— 1895	—	607	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1940	75	598	—	—	.024	—	

66-2	Indian Creek No. 1	Indian Creek	Beaver, Utah	12.0	11.95	— 1898	—	318	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	42	299	—	—	.038	—	
66-3	Rocky Ford	Beaver River	do	510	508	Feb. 1915	—	23,260	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	25.8	21,509	—	—	.134	—	
66-4	Rocky Ford	Sevier River	Sigurd, Utah	900	900	— 1890	—	2,115	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	50	790	—	—	.029	—	
66-5	Skutumpah	Skutumpah Creek	Salina, Utah	10.0	9.92	— 1893	—	667	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	47	430	—	—	.508	—	
66-6	Enterprise	Pine Creek	Enterprise, Utah	25.0	23.4	— 1909	—	9,000	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	31	8,550	—	—	.620	—	
66-7	Yankee Meadows	Pole Creek	Parowan, Utah	7.0	6.9	Dec. 1926	—	2,500	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1940	14	2,200	—	—	3.10	—	
66-8	Piute	Sevier River	Marysville, Utah	2,440	2,436	— 1910[5]	—	81,200	—	—	—	—	SCS
	do	do	do	—	—	— 1938	28	74,010	—	—	.106	—	
66-9	Sevier Bridge	do	Nephi, Utah	5,120	1,089	— 1908	—	250,000	—	—	—	—	SCS
	do	do	do	—	—	— 1932	24	234,462	—	—	.594	—	
66-10	Chalk Creek Debris Basin	Chalk Creek	Fillmore, Utah	60.8	*60	July 1936	.5	44.12	.002	*70	[6].73	1,112.9	SCS
	do	do	do	—	—	— 1946	10	0	0	*75	[7].14	228.7	
	do	do	do	—	—	Mar. 1955	8.5	0	0	75	—	—	
66-11a	Fiddlers Canyon Debris Basin	Fiddlers Canyon	Cedar City, Utah	12.6	12.6	— 1947	—	—	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1956	9	*15.00	*.089	*70	[8].145	221	
66-12a	Mill Canyon Retarding Structure	Mill Canyon	Glenwood, Utah	19.5	19.5	Dec. 1957	—	208	*1.600	—	—	—	SCS
	do	do	do	—	—	Dec. 1960	3	186	*1.431	*70	.38	578	

GREAT BASIN (NORTHWESTERN PART IN CALIFORNIA, NEVADA AND OREGON)

67-

GREAT BASIN
Humboldt, Carson, and Truckee River Basins

68-1	Willow Creek	Willow Creek	Elko, Nev.	112	111	— 1924	—	15,300	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1939	15	15,050	—	—	.15	—	
68-2	Elko Summit Reservoir No. 1	(ephemeral)	do	1.25	1.25	Mar. 1941	—	7.44	.223	—	—	—	SCS
	do	do	do	—	—	Aug. 1963	22.4	6.38	.192	66	.04	57.5	
68-3	Elko Summit Reservoir No. 2	do	do	.63	.63	Aug. 1945	—	5.45	.324	—	—	—	SCS
	do	do	do	—	—	Aug. 1963	18	4.96	.295	66.9	.05	73	
68-4	Dorsey Creek Reservoir	Dorsey Creek	do	9.16	9.14	Oct. 1952	—	131	.358	—	—	—	SCS
	do	do	do	—	—	Sept. 1963	10.9	128	.350	56.9	[8].12	[8]149	

GREAT BASIN
Owens, Walker, and Mono Lake Drainages

69-1	Weber	Walker River	Shurz, Nev.	2,800	2,440	Sept. 1935	—	13,200	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1939	4	12,980	—	—	.02	—	

SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE

70-1a	Fullerton Flood-Control Basin	Fullerton Creek	Brea, Calif.	[9]5.05	[9]4.95	Oct. 1941	—	753.5	—	—	—	—	CE
	do	do	do	—	—	Nov. 1944	3.1	743.0	—	—	.69	—	
	do	do	do	—	—	Mar. 1962	17.3	706.3	—	—	.42	—	
70-2	Lake Hodges	San Diequito River	Escondido, Calif.	303	301	Jan. 1919	—	36,601	—	—	—	—	SCS
	do	do	do	—	—	July 1935	16.5	34,779	—	*65	.365	517	
	do	do	do	—	—	July 1948	13.0	33,482	—	—	.332	470	
70-3	Railroad Canyon	San Jacinto River	Elsinore, Calif.	718	651	May 1928	—	12,218	—	—	—	—	SCS
	do	do	do	—	—	June 1939	11	12,034	—	*60	.03	39	
70-4	Lake Sherwood	Triunfo Creek	Hollywood, Calif.	16	15.7	— 1905	—	2,870	—	—	—	—	SCS
	do	do	do	—	—	Mar. 1936	31	2,792	—	*50	.16	174	
	do	do	do	—	—	Mar. 1938	2	2,772	—	—	.64	697	
70-5	Stone Canyon	Stone Canyon Creek	Sawtelle, Calif.	1.36	1.16	May 1921	—	7,998	—	—	—	—	SCS
	do	do	do	—	—	June 1939	18.1	7,949	—	*60	2.34	3,058	
70-6	Bonita Canyon	Bonita Creek	Orange, Calif.	4.00	4.00	Jan. 19[illegible]	—	326	—	—	—	—	SCS
	do	do	do	—	—	June 1939	[10]2	305	—	*60	2.63	3,437	

[1] Dam was raised about 6 ft. in 1952.
[2] Includes above crest deposits.
[3] Formed by original rock-filled dam 58 feet high, which was subsequently raised in 1900, 1902, and 1916.
[4] Computed from Size analysis.
[5] Original survey made in 1908.
[6] Basin filled with sediment by one summer flash flood.
[7] Has no meaning as a large portion of the sediment passed through the basin.
[8] Includes some deposition above crest of spillway.
[9] Drainage area and sediment contributing area were increased when Loftus diversion channel was completed on Dec. 21, 1954.
[10] Based on runoff seasons.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)													
70-7	Bouquet Canyon	Bouquet Creek	San Fernando, Calif.	12.6	11.6	Mar. 1934	--	36,900	--	--	--	--	SCS
	do	do	do	--	--	June 1939	1/5	36,436	--	*40	1.10	958	
70-8a	Chatsworth	Trib. of Los Angeles Rive-	do	5.40	4.45	Apr. 1918	--	10,125	--	--	--	--	SCS
	do	do	do	--	--	June 1939	21	10,077	--	*40	.51	444	
70-9	Lake Hemet	Trib. of San Jacinto River	Hemet, Calif.	66.0	65.3	-- 1892	--	14,000	--	--	--	--	SCS
	do	do	do	--	--	June 1940	48	11,702	--	*75	.73	1,190	
70-10	Laguna	Trib. of Newport Bay	Orange, Calif.	.75	.72	Feb. 1938	--	274	--	--	--	--	SCS
	do	do	do	--	--	June 1939	1/2	266	--	*40	5.56	4,840	
70-11	Encino	Encino Creek	Los Angeles, Calif.	1.42	1.30	May 1921	--	3,229	--	--	--	--	SCS
	do	do	do	--	--	June 1939	18	3,210	--	*40	.815	710	
70-12	Fairmont	Antelope Valley River	Lancaster, Calif.	2.64	2.37	Oct. 1913	--	7,487	--	--	--	--	SCS
	do	do	do	--	--	June 1939	1/26	7,393	--	--	1.53	--	
70-13b	Little Rock Irrigation Dist.	Little Rock Creek	Palmdale, Calif.	68.0	67.84	Apr. 1924	--	4,217	--	--	--	--	SCS
	do	do	do	--	--	Jan. 1936	1/11.0	4,139	--	*85	.10	185	
	do	do	do	--	--	June 1938	3.0	3,648	--	--	2.41	4,460	
	do	do	do	--	--	Oct. 1943	5.0	3,404	--	--	.72	1,330	
	do	do	do	--	--	Dec. 1946	3.0	3,352	--	--	.25	460	
	do	do	do	--	--	Oct. 1951	5.0	3,297	--	*85	.15	278	
	do	do	do	--	--	Aug. 1953	2.2	3,313	--	*85	2/--	2/--	
70-14a	Live Oak Dam	Live Oak Creek	LaVerne, Calif.	2.3	2.3	-- 1919 3/	--	247	--	--	--	--	CE
	do	do	do	--	--	Mar. 1929	6.3	247	--	--	0	--	
	do	do	do	--	--	Mar. 1936	7.0	242	--	--	.31	--	
	do	do	do	--	--	May 1938	2.1	228	--	--	2.90	--	
	do	do	do	--	--	Nov. 1952	14.5	221	--	--	.21	--	
	do	do	do	--	--	Dec. 1961	9.0	170	--	--	2.46	--	
	do	do	do	--	--	Dec. 1962	1.0	166	--	--	1.74	--	
	do	do	do	--	--	Mar. 1967	4.3	4/221.8	1.33	--	2.83	--	
	do	do	do	--	--	Jan. 1969	1.75	197.1	1.11	--	6.13	--	
	do	do	do	--	--	Oct. 1970	1.75	251.1	1.13	--	5.70	--	
70-15	Morena	Cottonwood Creek	San Diego, Calif.	112.0	109.4	Mar. 1910	--	66,767	--	--	--	--	SCS
	do	do	do	--	--	Dec. 1935	25.7	60,699	--	*60	2.16	2,823	
	do	do	do	--	--	July 1948	12.6	58,933	--	--	1.28	1,673	
70-16b	Prado Flood-Control Reservoir	Santa Ana River	Corona, Calif.	2,233	1,131	Sept. 1941	--	222,840	--	--	--	--	CE
	do	do	do	--	--	Aug. 1960	18.9	216,960	--	--	.275	--	
70-17	Mockingbird Canyon 5/	Mockingbird Canyon	Arlington, Calif.	11.6	11.5	-- 1914	--	*1,000	--	--	--	--	SCS
	do	do	do	--	--	Mar. 1940	26	961	--	*60	.130	170	
70-18a	Hansen Flood-Control Basin	Tujunga Creek	San Fernando, Calif.	147	146	Sept. 1940	--	35,800	2.06	--	--	--	CE
	do	do	do	--	--	July 1941	.8	35,200	2.02	--	4.10	--	
	do	do	do	--	--	Oct. 1943	2.3	34,100	1.96	--	3.78	--	
	do	do	do	--	--	Nov. 1945	2.1	33,500	1.92	--	2.06	--	
	do	do	do	--	--	Jan. 1962	16.2	33,265	1.91	--	.10	--	
	do	do	do	--	--	Aug. 1969	7.58	29,700	1.71	--	3.22	--	
70-19	Brea F. C. Basin	Brea Creek	Fullerton, Calif.	23.4	23.1	Mar. 1942	--	4,168	3.97	--	--	--	CE
	do	do	do	--	--	Oct. 1949	7.5	4,097	3.90	--	.41	--	
70-20c	Cogswell (San Gabriel Dam #2)	San Gabriel River	Azusa, Calif.	39.2	39.0	Apr. 1935	--	12,881	--	--	--	--	CE
	do	do	do	--	--	Jan. 1936	.8	12,298	--	--	--	--	
	do	do	do	--	--	Apr. 1938	2.2	10,786	--	--	17.6	--	
	do	do	do	--	--	Nov. 1939	1.6	11,029	--	--	6/--	--	
	do	do	do	--	--	Nov. 1940	1.0	11,102	--	--	6/--	--	
	do	do	do	--	--	Nov. 1941	1.0	10,915	--	--	4.79	--	
	do	do	do	--	--	Oct. 1943	1.9	10,501	--	--	5.59	--	
	do	do	do	--	--	Jan. 1945	1.2	10,536	--	--	6/--	--	
	do	do	do	--	--	Sept. 1946	1.7	10,597	--	--	6/--	--	
	do	do	do	--	--	Sept. 1947	1.0	10,634	--	--	6/--	--	
	do	do	do	--	--	Dec. 1957	10.2	10,585	--	--	.12	--	
	do	do	do	--	--	Oct. 1958	.7	10,446	.612	--	2.48	--	
	do	do	do	--	--	Nov. 1962	4.1	10,228	.643	--	1.4	--	
	do	do	do	--	--	June 1966	3.7	9,999	.642	--	1.62	--	
	do	do	do	--	--	Mar. 1969	2.75	9,339	.512	--	6.15	--	
70-21d	San Gabriel Dam No. 1	do	do	203	7/203	-- 1937	--	8/53,344	--	--	--	--	CE
	do	do	do	--	--	Oct. 1938	.9	47,191	--	--	28.3	--	
	do	do	do	--	--	Nov. 1940	2.1	46,335	--	--	1.68	--	
	do	do	do	--	--	Sept. 1941	.8	45,862	--	--	--	--	
	do	do	do	--	--	Oct. 1942	1.0	45,759	--	--	.43	--	
	do	do	do	--	--	Sept. 1943	1.0	44,032	--	--	7.13	--	
	do	do	do	--	--	Oct. 1944	1.1	44,388	--	--	--	--	
	do	do	do	--	--	Nov. 1945	1.0	44,342	--	--	.19	--	
	do	do	do	--	--	Nov. 1948	3.0	43,825	--	--	.97	--	
	do	do	do	--	--	Nov. 1951	3.0	43,928	--	--	.23	--	
	do	do	do	--	--	Jan. 1953	1.2	43,853	--	--	.94	--	

	do	do	do	--	--	May	1954	1.3	44,013	--	--	.127	--	
	do	do	do	--	--	Aug.	1958	4.3	44,614	--	--	.193	--	
	do	do	do	--	--	Sept.	1961	3.1	44,366	--	--	.329	--	
	do	do	do	--	--	Nov.	1962	1.2	43,642	.51	--	2.49	--	
	do	do	do	--	--	Dec.	1965	3.1	42,371	.49	--	2.02	--	
	do	do	do	--	--	Apr.	1966	.3	42,075	.51	--	--	--	
	do	do	do	--	--	Aug.	1967	1.3	40,697	.46	--	5.22	--	
	do	do	do	--	--	Feb.	1969	1.5	38,778	.45	--	8.86	--	
	do	do	do	--	--	May	1969	.25	36,748	.42	--	--	--	
	do	do	do	--	--	Oct.	1969	.42	37,822	.43	--	--	--	
	do	do	do	--	--	Oct.	1970	1.0	41,549	.48	--	--	--	
70-22b	Morris Reservoir	do	do	211.3	9/210.7	Jan.	1934	--	39,316	--	--	--	--	[illegible]
	do	do	do	--	--	Jan.	1936	2.1	38,692	.45	--	1.41	--	
	do	do	do	--	--	Feb.	1938	2.1	37,175	.43	--	3.43	--	
	do	do	do	--	--	Oct.	1938	.7	36,655	.43	--	3.53	--	
	do	do	do	--	--	Dec.	1949	11.2	35,174	.41	--	.63	--	
	do	do	do	--	--	Sept.	1956	6.8	34,861	.41	--	.22	--	
	do	do	do	--	--	Nov.	1960	4.2	33,827	.40	--	1.17	--	
	do	do	do	--	--	Jan.	1967	6.2	32,961	.39	--	.66	--	
	do	do	do	--	--	Oct.	1970	3.8	30,085	.35	--	3.59	--	
70-23b	San Dimas F. C. Basin	San Dimas Wash	San Dimas, Calif.	16.2	16.1	Sept.	1922	--	4/1,496	--	--	--	--	[illegible]
	do	do	do	--	--	Dec.	1935	13.2	1,373	--	--	.58	--	
	do	do	do	--	--	Oct.	1938	2.9	1,155	--	--	4.67	--	
	do	do	do	--	--	Nov.	1939	1.0	1,189	--	--	--	--	
	do	do	do	--	--	Dec.	1941	2.1	1,145	--	--	1.30	--	
	do	do	do	--	--	Oct.	1943	1.9	1,071	--	--	2.42	--	
	do	do	do	--	--	Nov.	1944	1.0	1,042	--	--	1.80	--	
	do	do	do	--	--	Oct.	1954	9.8	1,025	--	--	.11	--	
	do	do	do	--	--	Nov.	1961	7.1	705	.25	--	2.80	--	
	do	do	do	--	--	Apr.	1962	.4	729	.28	--	--	--	
	do	do	do	--	--	Aug.	1966	4.3	1,234	.49	--	16.0	--	
	do	do	do	--	--	Apr.	1967	.7	1,129	.35	--	--	--	
	do	do	do	--	--	Jan.	1969	1.75	847	.32	--	10.0	--	
	do	do	do	--	--	Feb.	1969	.08	756	.29	--	--	--	
	do	do	do	--	--	Nov.	1970	1.75	1,515	.47	--	1.12	--	
70-24c	Puddingstone Diversion Dam	do	do	19.9	10/19.7	Oct.	1929	--	4/148	.06	--	--	--	[illegible]
	do	do	do	--	--	Jan.	1936	6.25	121	.05	--	1.66	--	
	do	do	do	--	--	Mar.	1938	2.17	50	.02	--	12.58	--	
	do	do	do	--	--	Nov.	1939	1.66	76	.03	--	--	--	
	do	do	do	--	--	Oct.	1942	2.92	101	.04	--	--	--	
	do	do	do	--	--	Sept.	1944	1.92	112	.05	--	--	--	
	do	do	do	--	--	Jan.	1952	7.33	119	.05	--	--	--	
	do	do	do	--	--	Sept.	1953	1.67	138	.06	--	--	--	
	do	do	do	--	--	Sept.	1962	9.0	203	.09	--	.28	--	
	do	do	do	--	--	May	1966	3.67	125	.05	--	1.07	--	
	do	do	do	--	--	Oct.	1967	1.41	200	.08	--	2.03	--	
	do	do	do	--	--	Jan.	1969	1.25	74	.03	--	5.13	--	
	do	do	do	--	--	Mar.	1969	.17	42	.02	--	--	--	
	do	do	do	--	--	Nov.	1970	1.66	156.3	.07	--	1.69	--	
70-25a	Puddingstone Dam F. C. Basin	Puddingstone Creek	do	32.2	11/11.0	--	1915	--	17,398	--	--	--	--	[illegible]
	do	do	do	--	--	--	1927	0	17,398	--	--	--	--	
	do	do	do	--	--	Jan.	1941	13	17,190	--	--	1.45	--	
70-26c	Big Dalton F. C. Basin	Big Dalton Creek	Glendora, Calif.	4.5	4.5	Jan.	1930	--	4/1,194	--	--	--	--	[illegible]
	do	do	do	--	--	Sept.	1931	1.7	1,039	--	--	20.26	--	
	do	do	do	--	--	Jan.	1935	3.3	1,053	--	--	--	--	
	do	do	do	--	--	Mar.	1938	3.1	969	--	--	6.02	--	
	do	do	do	--	--	Sept.	1943	5.5	953	--	--	.65	--	
	do	do	do	--	--	Oct.	1944	1.0	952	--	--	.22	--	
	do	do	do	--	--	Oct.	1958	14.0	951	--	--	.02	--	
	do	do	do	--	--	Nov.	1961	3.1	880	1.25	--	5.09	--	
	do	do	do	--	--	Jan.	1962	.2	869	1.24	--	--	--	
	do	do	do	--	--	Aug.	1966	4.7	752	1.14	--	5.53	--	
	do	do	do	--	--	Apr.	1967	.7	692	1.05	--	--	--	
	do	do	do	--	--	Jan.	1969	1.75	515	.78	--	.225	--	
	do	do	do	--	--	Mar.	1969	.17	452	.68	--	--	--	

1/ Based on runoff seasons.
2/ Not computed because of scour during period.
3/ Normal operation began 1922.
4/ Sediment removed at various times.
5/ Equalizing reservoir on Gage Canal System obtaining water from the Santa Ana River.
6/ No record of quantities sluiced.
7/ Includes San Gabriel Dams drainage area 39.2 sq. mi. as sediment is sluiced into San Gabriel Dam 1 drainage area.
8/ Storage capacity is regained by sluicing at various times.
9/ Includes Cogswell and San Gabriel Dam #1. (Drainage area 203 sq. mi.) Sediment sluiced into this area.
10/ Includes San Dimas drainage area (16.2 sq. mi.). Sediment sluiced into this area.
11/ 21.1 sq. mi. controlled by San Dimas, Live Oak Dam, and Puddingstone Diversion Dams.
* Estimated or assumed.

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SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
			SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)										
70-27a	Big Santa Anita F. C. Basin	Santa Anita Creek	Arcadia, Calif.	10.8	10.8	— 1923	—	1/1,376	—	—	—	—	CE
	-do-	-do-	-do-	—	—	Feb. 1935 2/	7.9	1,068	—	—	3.61	—	
	-do-	-do-	-do-	—	—	Feb. 1936	1.0	1,014	—	—	5.00	—	
	-do-	-do-	-do-	—	—	July 1938	2.4	688	—	—	12.6	—	
	-do-	-do-	-do-	—	—	Feb. 1940	1.6	710	—	—	7.18	—	
	-do-	-do-	-do-	—	—	Feb. 1942	2.0	701	—	—	1.43	—	
	-do-	-do-	-do-	—	—	Mar. 1943	1.1	568	—	—	11.2	—	
	-do-	-do-	-do-	—	—	Sept. 1943	.5	604	—	—	—	—	
	-do-	-do-	-do-	—	—	May 1944	.7	697	—	—	—	—	
	-do-	-do-	-do-	—	—	Jan. 1947	2.7	728	—	—	.44	—	
	-do-	-do-	-do-	—	—	Dec. 1952	5.9	728	—	—	.22	—	
	-do-	-do-	-do-	—	—	July 1954	1.6	584	—	—	9.15	—	
	-do-	-do-	-do-	—	—	Feb. 1956	1.5	613	—	—	1.30	—	
	-do-	-do-	-do-	—	—	Sept. 1958	2.6	587	—	—	.94	—	
	-do-	-do-	-do-	—	—	Apr. 1962	3.6	630	.16	—	3.31	—	
	-do-	-do-	-do-	—	—	Sept. 1966	4.4	552	.14	—	1.90	—	
	-do-	-do-	-do-	—	—	Oct. 1968	2.1	600	.14	—	3.09	—	
	-do-	-do-	-do-	—	—	Mar. 1969	.42	298	.06	—	—	—	
	-do-	-do-	-do-	—	—	Nov. 1970	1.67	836	.16	—	.94	—	
70-28c	Big Tujunga F. C. Basin	Big Tujunga Creek	Sunland, Calif.	82.3	82.2	— 1931	—	1/6,240	—	—	—	—	CE
	-do-	-do-	-do-	—	—	May 1938	6.9	4,734	—	—	2.65	—	
	-do-	-do-	-do-	—	—	Oct. 1939	1.5	4,488	—	—	2.00	—	
	-do-	-do-	-do-	—	—	Feb. 1940	.3	4,568	—	—	2.64	—	
	-do-	-do-	-do-	—	—	July 1941	1.5	4,625	—	—	7.33	—	
	-do-	-do-	-do-	—	—	Feb. 1943	1.5	4,043	—	—	3.10	—	
	-do-	-do-	-do-	—	—	Apr. 1943	.2	4,236	.28	—	—	—	
	-do-	-do-	-do-	—	—	June 1944	1.1	4,235	.28	—	2.19	—	
	-do-	-do-	-do-	—	—	Oct. 1953	9.3	4,099	.27	—	.18	—	
	-do-	-do-	-do-	—	—	June 1958	4.8	4,123	.27	—	.28	—	
	-do-	-do-	-do-	—	—	July 1962	4.1	4,065	.26	—	.40	—	
	-do-	-do-	-do-	—	—	Oct. 1966	4.25	3,819	.25	—	.71	—	
	-do-	-do-	-do-	—	—	Feb. 1969	2.33	2,758	.18	—	6.03	—	
	-do-	-do-	-do-	—	—	Oct. 1970	1.67	6,027	.39	—	—	—	
70-29b	Devil's Gate F. C. Basin	Arroyo Seco River	Pasadena, Calif.	31.9	31.7	— 1916	—	1/4,601	—	—	—	—	CE
	-do-	-do-	-do-	—	—	June 1933	13.0	4,554	—	—	.11	—	
	-do-	-do-	-do-	—	—	Sept. 1934	1.2	4,127	—	—	11.15	—	
	-do-	-do-	-do-	—	—	Jan. 1935	.3	3,996	—	—	13.69	—	
	-do-	-do-	-do-	—	—	June 1938	3.5	2,967	—	—	9.22	—	
	-do-	-do-	-do-	—	—	Jan. 1942	3.6	2,728	—	—	2.08	—	
	-do-	-do-	-do-	—	—	Jan. 1943	1.0	2,506	.38	—	5.02	—	
	-do-	-do-	-do-	—	—	Fall 1948	5.7	2,561	.39	—	1.25	—	
	-do-	-do-	-do-	—	—	July 1952	3.8	2,630	.40	—	1.86	—	
	-do-	-do-	-do-	—	—	Sept. 1955	3.3	2,709	.41	—	.58	—	
	-do-	-do-	-do-	—	—	Dec. 1959	4.2	2,839	.43	—	.63	—	
	-do-	-do-	-do-	—	—	May 1961	1.4	2,886	.44	—	4.07	—	
	-do-	-do-	-do-	—	—	May 1962	1.0	2,749	.42	—	9.59	—	
	-do-	-do-	-do-	—	—	Sept. 1966	4.3	2,598	.50	—	4.20	—	
	-do-	-do-	-do-	—	—	Nov. 1969	3.2	2,002	.30	—	7.32	—	
70-30d	Eaton Wash (Eaton Wash Dam)	Eaton Creek	-do-	9.5	9.4	— 1936	—	1/956	—	—	—	—	CE
	-do-	-do-	-do-	—	—	Feb. 1937	1.0	945	—	—	1.17	—	
	-do-	-do-	-do-	—	—	May 1938	1.3	698	—	—	20.2	—	
	-do-	-do-	-do-	—	—	Dec. 1938	.6	699	—	—	—	—	
	-do-	-do-	-do-	—	—	Oct. 1940	1.8	711	—	—	—	—	
	-do-	-do-	-do-	—	—	Aug. 1941	.8	681	—	—	—	—	
	-do-	-do-	-do-	—	—	Sept. 1942	1.1	722	—	—	—	—	
	-do-	-do-	-do-	—	—	Oct. 1943	1.1	632	.29	—	12.7	—	
	-do-	-do-	-do-	—	—	Oct. 1944	1.0	607	.27	—	2.7	—	
	-do-	-do-	-do-	—	—	Oct. 1946	2.0	674	.31	—	0	—	
	-do-	-do-	-do-	—	—	June 1947	.7	661	.30	—	2.0	—	
	-do-	-do-	-do-	—	—	June 1950	3.0	665	.30	—	0	—	
	-do-	-do-	-do-	—	—	Jan. 1952	1.6	703	.32	—	0.1	—	
	-do-	-do-	-do-	—	—	May 1957	5.3	655	.30	—	1.0	—	
	-do-	-do-	-do-	—	—	Nov. 1958	1.5	725	.33	—	.50	—	
	-do-	-do-	-do-	—	—	Sept. 1961	2.9	807	.37	—	2.68	—	
	-do-	-do-	-do-	—	—	Oct. 1963	2.0	828	.37	—	.53	—	
	-do-	-do-	-do-	—	—	Feb. 1964	.2	872.8	.40	—	—	—	
	-do-	-do-	-do-	—	—	Apr. 1966	2.2	769.7	.35	—	4.98	—	
	-do-	-do-	-do-	—	—	July 1967	1.3	758.4	.34	—	6.49	—	
	-do-	-do-	-do-	—	—	Dec. 1969	2.6	879	.40	—	11.3	—	

70-31c	Pacoima F. C. Basin	Pacoima Canyon	San Fernando, Calif.	28.2	28.2	Oct.	1929	—	1/6,060	—	—	—	—	CE
	do	do	do	--	--	Jan.	1936	6.3	5,592	—	—	2.63	—	
	do	do	do	--	--	Mar.	1938	2.2	5,004	—	—	9.47	—	
	do	do	do	--	--	Oct.	1942	4.6	4,837	—	—	1.29	—	
	do	do	do	--	--	Dec.	1944	2.1	4,714	—	—	2.84	—	
	do	do	do	--	--	Oct.	1954	9.8	4,787	—	—	.15	—	
	do	do	do	--	--	June	1958	3.8	4,651	—	—	2.97	—	
	do	do	do	--	--	May	1962	3.9	4,581	.83	—	.64	—	
	do	do	do	--	--	Aug.	1966	4.25	4,453	.81	—	1.08	—	
	do	do	do	--	--	Mar.	1969	2.58	3,841	.70	—	8.40	—	
70-32	Santiago	Santiago Creek	Villa Park, Calif.	[illegible]	62.1	Dec.	1931	—	25,000	1.619	—	—	—	CE
	do	do	do	--	--	Sept.	1968	16.8	24,840	1.609	—	.15	—	
70-33b	Sawpit F. C. Basin	Sawpit Creek	Monrovia, Calif.	3.3	3.3	—	19232/	--	1/476	—	—	--	—	CE
	do	do	do	--	—	Oct.	1935	8.3	389	—	—	3.18	—	
	do	do	do	--	--	May	1938	2.6	320	—	—	8.03	—	
	do	do	do	--	--	May	1941	3.0	342	—	—	2.94	—	
	do	do	do	--	--	Dec.	1943	2.6	322	—	—	3.03	—	
	do	do	do	--	--	Mar.	1954	10.2	305	—	—	.51	—	
	do	do	do	--	--	Sept.	1959	5.5	289	—	—	3.03	—	
	do	do	do	--	—	May	1962	2.7	271.8	.52	—	1.91	—	
	do	do	do	--	--	Aug.	1964	2.2	308.5	.61	—	5.09	—	
	do	do	do	--	--	July	1966	1.9	284.3	.55	—	3.82	—	
	do	do	do	--	--	May	1967	.7	269.2	.48	—	—	—	
	do	do	do	--	--	Nov.	1969	2.7	391.0	.47	—	16.39	—	
70-34b	Sierra Madre Debris Dam	Little Santa Anita Creek	Sierra Madre, Calif.	2.39	2.39	Feb.	1928	--	1/50.3	--	--	—	—	CE
	do	do	do	--	--	Feb.	1930	2.0	50.3	--	—	—	—	
	do	do	do	--	--	Feb.	1932	2.0	47.4	—	—	.61	—	
	do	do	do	--	—	Nov.	1939	7.8	34.4	—	—	.70	--	
	do	do	do	--	--	Jan.	1944	4.1	44.3	—	--	--	--	
	do	do	do	--	--	Oct.	1944	.8	42.4	—	--	1.00	--	
	do	do	do	--	--	Oct.	1956	12.0	40.6	—	--	1.95	--	
	do	do	do	--	--	Sept.	1969	13.0	--	—	—	4/2.10	--	
	do	do	do	--	--	Sept.	1970	1.0	—	—	—	1.53	—	
70-35b	Thompson Creek F. C. Basin	Thompson Creek	Claremont, Calif.	3.5	3.5	--	1916	—	1/692	3.51	—	--	—	CE
	do	do	do	--	--	Oct.	1932	5/4.6	643	3.26	—	3.04	--	
	do	do	do	--	--	Jan.	1943	10.3	612	3.11	—	.86	--	
	do	do	do	--	--	Sept.	1954	11.7	571	2.90	—	1.00	--	
	do	do	do	--	--	Jan.	1957	3.3	566	2.87	—	.86	—	
	do	do	do	--	--	June	1957	.4	570	2.89	--	--	--	
	do	do	do	--	--	Dec.	1959	1.5	578	2.93	--	—	--	
	do	do	do	--	--	July	1962	2.6	554	2.81	—	2.64	—	
	do	do	do	--	--	Feb.	1967	4.6	510	2.59	—	2.73	--	
	do	do	do	--	--	Feb.	1969	2.0	448	2.27	--	8.93	--	
70-36c	Wilbur Ave. Debris Basin	Aliso Creek	Northridge, Calif.	8.63	8.63	June	1942	--	1/--	—	—	4/--	—	CE
	do	do	do	--	--	Sept.	1943	1.33	--	—	--	2.37	--	
	do	do	do	--	--	Sept.	1944	1	--	—	—	2.72	—	
	do	do	do	--	--	Sept.	1947	3.0	—	—	—	.85	--	
	do	do	do	--	--	Sept.	1950	3.0	—	--	--	.25	—	
	do	do	do	--	--	Sept.	1952	2	—	--	--	2.09	—	
	do	do	do	--	--	Sept.	1957	5	--	—	--	.47	--	
	do	do	do	--	--	Sept.	1960	3	—	--	—	.90	--	
	do	do	do	--	—	Sept.	1962	2	--	—	—	1.29	--	
	do	do	do	--	--	Sept.	1965	3	--	—	—	.41	--	
	do	do	do	--	--	Sept.	1966	1	—	--	—	3.99	—	
	do	do	do	--	--	Sept.	1967	1	—	--	--	2.35	—	
	do	do	do	--	--	Sept.	1968	1	—	--	--	2.17	—	
	do	do	do	--	--	Sept.	1969	1	--	--	--	2.72	--	
70-37b	Altadena Debris Basin	Rubio Wash	Altadena, Calif.	.65	.65	Sept.	1947	1	1/--	—	--	4/1.34	—	CE
	do	do	do	--	--	Sept.	1948	1	--	—	--	1.92	--	
	do	do	do	--	--	Sept.	1949	1	—	—	--	1.35	--	
	do	do	do	--	—	Sept.	1950	1	--	—	--	1.58	--	
	do	do	do	--	--	Mar.	1952	1.5	—	--	--	1.75	--	
	do	do	do	--	—	Feb.	1956	3.9	--	--	--	1.11	--	
	do	do	do	--	--	Sept.	1957	1.6	--	—	--	1.23	--	
	do	do	do	--	--	Apr.	1958	.6	—	—	--	8.97	--	
	do	do	do	--	--	Sept.	1959	1.4	—	—	--	2.57	--	

1/ Sediment is removed at various times by sluicing and/or excavation.
2/ Date normal operation began - Mar. 1927.
3/ Date normal operation began - June 1927.

4/ Sedimentation values as computed by Los Angeles County FCD are based on complete water year.
5/ Storage and surface area assumed same at time of initial normal operations, Mar. 1928 as in 1916 survey.
* Estimated or assumed.

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SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)													
70-38c	Bailey Debris Dam	Bailey Channel	Sierra Madre, Calif.	0.60	0.60	Sept. 1946	1	1/--	--	--	2/0.84	--	CE
	--do--	--do--	--do--	--	--	Sept. 1947	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1948	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1949	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1950	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1952	2	--	--	--	.18	--	
	--do--	--do--	--do--	--	--	Sept. 1959	4.8	--	--	--	2.88	--	
	--do--	--do--	--do--	--	--	Sept. 1962	3.0	--	--	--	8.83	--	
	--do--	--do--	--do--	--	--	Sept. 1968	6.0	--	--	--	.86	--	
	--do--	--do--	--do--	--	--	Sept. 1970	2.0	--	--	--	2.33	--	
70-39c	Brand Debris Basin	Brand Canyon Channel	La Canada, Calif.	1.03	1.03	Sept. 1940	5	1/--	--	--	2/.58	--	CE
	--do--	--do--	--do--	--	--	Sept. 1941	1	--	--	--	.63	--	
	--do--	--do--	--do--	--	--	Sept. 1942	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1943	1	--	--	--	1.86	--	
	--do--	--do--	--do--	--	--	Sept. 1944	1	--	--	--	.19	--	
	--do--	--do--	--do--	--	--	Sept. 1945	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1946	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1947	1	--	--	--	.09	--	
	--do--	--do--	--do--	--	--	Sept. 1948	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1949	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1950	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1952	2	--	--	--	1.59	--	
	--do--	--do--	--do--	--	--	Sept. 1964	12	--	--	--	1.17	--	
	--do--	--do--	--do--	--	--	Sept. 1965	1	--	--	--	27.86	--	
	--do--	--do--	--do--	--	--	Sept. 1970	5	--	--	--	2.87	--	
70-40c	Dunsmuir Debris Basin	Dunsmuir Canyon Channel	Tujunga, Calif.	.84	.84	Sept. 1936	1	1/--	--	--	2/.69	--	CE
	--do--	--do--	--do--	--	--	Sept. 1938	2	--	--	--	29.0	--	
	--do--	--do--	--do--	--	--	Sept. 1940	2	--	--	--	8.14	--	
	--do--	--do--	--do--	--	--	Sept. 1941	1	--	--	--	8.74	--	
	--do--	--do--	--do--	--	--	Sept. 1942	1	--	--	--	.27	--	
	--do--	--do--	--do--	--	--	Sept. 1943	1	--	--	--	10.3	--	
	--do--	--do--	--do--	--	--	Sept. 1944	1	--	--	--	2.87	--	
	--do--	--do--	--do--	--	--	Sept. 1945	1	--	--	--	.56	--	
	--do--	--do--	--do--	--	--	Sept. 1946	1	--	--	--	3.13	--	
	--do--	--do--	--do--	--	--	Sept. 1947	1	--	--	--	1.15	--	
	--do--	--do--	--do--	--	--	Sept. 1948	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1949	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1950	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1952	2	--	--	--	4.07	--	
	--do--	--do--	--do--	--	--	Sept. 1954	2	--	--	--	.36	--	
	--do--	--do--	--do--	--	--	Sept. 1959	5	--	--	--	3.17	--	
	--do--	--do--	--do--	--	--	Sept. 1970	11	--	--	--	1.58	--	
70-41c	Eagle Debris Basin	Eagle Canyon	La Crescenta, Calif.	.61	.61	Sept. 1938	2	1/--	--	--	2/21.2	--	CE
	--do--	--do--	--do--	--	--	Sept. 1939	1	--	--	--	11.7	--	
	--do--	--do--	--do--	--	--	Sept. 1941	2	--	--	--	7.03	--	
	--do--	--do--	--do--	--	--	Sept. 1942	1	--	--	--	.34	--	
	--do--	--do--	--do--	--	--	Sept. 1943	1	--	--	--	13.7	--	
	--do--	--do--	--do--	--	--	Sept. 1944	1	--	--	--	4.99	--	
	--do--	--do--	--do--	--	--	Sept. 1945	1	--	--	--	1.11	--	
	--do--	--do--	--do--	--	--	Sept. 1946	1	--	--	--	.59	--	
	--do--	--do--	--do--	--	--	Sept. 1947	1	--	--	--	.41	--	
	--do--	--do--	--do--	--	--	Sept. 1948	1	--	--	--	.07	--	
	--do--	--do--	--do--	--	--	Sept. 1949	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1950	1	--	--	--	0	--	
	--do--	--do--	--do--	--	--	Sept. 1952	2	--	--	--	2.66	--	
	--do--	--do--	--do--	--	--	Aug. 1956	3.9	--	--	--	.02	--	
	--do--	--do--	--do--	--	--	Sept. 1960	4.1	--	--	--	1.67	--	
	--do--	--do--	--do--	--	--	Sept. 1961	1	--	--	--	2.05	--	
	--do--	--do--	--do--	--	--	Sept. 1966	5	--	--	--	5.28	--	
	--do--	--do--	--do--	--	--	Sept. 1970	4	--	--	--	5.87	--	
70-42d	Fair Oaks Debris Basin	Fair Oaks Canyon	Altadena, Calif.	.21	.21	Sept. 1936	1	1/--	--	--	2/46.4	--	CE
	--do--	--do--	--do--	--	--	Sept. 1938	2	--	--	--	47.6	--	
	--do--	--do--	--do--	--	--	Sept. 1941	3	--	--	--	3.9	--	
	--do--	--do--	--do--	--	--	Sept. 1943	2	--	--	--	4.8	--	
	--do--	--do--	--do--	--	--	Sept. 1944	1	--	--	--	.24	--	
	--do--	--do--	--do--	--	--	Sept. 1945	1	--	--	--	1.71	--	
	--do--	--do--	--do--	--	--	Sept. 1946	1	--	--	--	2.86	--	
	--do--	--do--	--do--	--	--	Sept. 1947	1	--	--	--	1.95	--	

	-----do-----	-----do-----	-----do-----	--	--	Sept. 1948	1	--	--	--	.019	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1949	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1952	2	--	--	--	4.57	--	
	-----do-----	-----do-----	-----do-----	--	--	Oct. 1956	4.1	--	--	--	.14	--	
	-----do-----	-----do-----	-----do-----	--	--	June 1958	1.7	--	--	--	19.05	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1963	5.2	--	--	--	4.76	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1966	3	--	--	--	10.14	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1968	2	--	--	--	3.10	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1969	1	--	--	--	46.9	--	
70-43b	Fern Debris Basin-----	Fern Canyon-----	-----do-----	.30	.30	Sept. 1936	1	1/--	--	--	2/31.2	--	CE
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1938	2	--	--	--	41.3	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1941	3	--	--	--	3.30	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1942	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1943	1	--	--	--	22.0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1944	1	--	--	--	6.17	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1945	1	--	--	--	3.07	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1946	1	--	--	--	2.77	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1947	1	--	--	--	.43	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1948	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1949	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1952	2	--	--	--	5.47	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1964	12	--	--	--	1.23	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1966	2	--	--	--	16.67	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1968	2	--	--	--	11.5	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1969	1	--	--	--	24.6	--	
70-44c	Gould Debris Basin-----	Gould Canyon Channel-----	La Canada, Calif.-----	.47	.47	Sept. 1948	1	1/--	--	--	2/0	--	CE
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	2	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1952	2	--	--	--	5.32	--	
	-----do-----	-----do-----	-----do-----	--	--	June 1958	5.8	--	--	--	3.29	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1962	4.2	--	--	--	5.83	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1966	4.0	--	--	--	9.04	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1968	2	--	--	--	1.98	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1969	1	--	--	--	28.7	--	
70-45a	Haines Debris Basin-----	Haines Canyon-----	Tujunga, Calif.-----	1.53	1.53	Sept. 1938	3	1/--	--	--	2/6.93	--	CE
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1940	2	--	--	--	2.31	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1941	1	--	--	--	5.09	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1943	2	--	--	--	4.22	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1944	1	--	--	--	3.58	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1945	1	--	--	--	2.59	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1946	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1947	1	--	--	--	.37	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1948	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1949	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	1	--	--	--	0	--	
	-----do-----	-----do-----	-----do-----	--	--	May 1952	1.6	--	--	--	1.57	--	
70-46c	Hall's Debris Basin-----	Hall - Beckley Canyon-----	La Canada, Calif.-----	3/.84	.84	Sept. 1936	1	1/--	--	--	2/17.2	--	CE
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1937	1	--	--	--	13.7	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1938	1	--	--	--	75.4	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1941	3	--	--	--	12.0	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1943	2	--	--	--	17.9	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1944	1	--	--	--	6.10	--	
	-----do-----	-----do-----	-----do-----	3/1.06	1.06	Sept. 1945	1	--	--	--	2.97	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1946	1	--	--	--	1.00	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1947	1	--	--	--	2.60	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1948	1	--	--	--	--	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1949	1	--	--	--	--	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1950	1	--	--	--	--	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1952	2	--	--	--	6.40	--	
	-----do-----	-----do-----	-----do-----	--	--	Feb. 1957	4.4	--	--	--	.14	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1959	2.6	--	--	--	11.03	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1962	3	--	--	--	.063	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1964	2	--	--	--	4.48	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1968	4	--	--	--	3.49	--	
	-----do-----	-----do-----	-----do-----	--	--	Sept. 1969	1	--	--	--	34.4	--	

1/ Capacity of debris basin varies. Debris excavated at various times.
2/ Sedimentation values as computed by LACFCD are based on complete water year.

3/ Drainage area 0.84 sq. mi. to 1945; 1.0659 sq. mi. beginning 1945.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE -FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
70-47c	Hay Debris Basin	Hay Canyon Channel	La Canada, Calif.	0.20	0.20	Sept. 1938	2	1/—	—	—	2/28.3	—	CE
	do	do	do	—	—	Sept. 1939	1	—	—	—	6.30	—	
	do	do	do	—	—	Sept. 1940	1	—	—	—	.55	—	
	do	do	do	—	—	Sept. 1941	1	—	—	—	1.90	—	
	do	do	do	—	—	Sept. 1943	2	—	—	—	4.75	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	.65	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	1.95	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1952	2	—	—	—	2.30	—	
	do	do	do	—	—	Sept. 1961	9	—	—	—	3.58	—	
	do	do	do	—	—	Sept. 1964	3	—	—	—	5.95	—	
	do	do	do	—	—	Sept. 1968	4	—	—	—	3.25	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	11.5	—	
70-48c	Las Flores Debris Basin	Las Flores Channel	Altadena, Calif.	.45	.45	Sept. 1936	1	1/—	—	—	2/14.7	—	CE
	do	do	do	—	—	Sept. 1938	2	—	—	—	30.2	—	
	do	do	do	—	—	Sept. 1939	1	—	—	—	1.53	—	
	do	do	do	—	—	Sept. 1943	4	—	—	—	4.80	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	3.75	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	.93	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	.96	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	.67	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1952	2	—	—	—	1.39	—	
	do	do	do	—	—	Sept. 1963	11	—	—	—	6.00	—	
	do	do	do	—	—	Sept. 1966	3	—	—	—	8.02	—	
	do	do	do	—	—	Sept. 1969	3	—	—	—	13.0	—	
70-49c	Lincoln Debris Basin	Lincoln Canyon	do	.90	.90	Sept. 1936	1	1/—	—	—	2/9.86	—	CE
	do	do	do	—	—	Sept. 1938	2	—	—	—	17.8	—	
	do	do	do	—	—	Sept. 1940	2	—	—	—	.90	—	
	do	do	do	—	—	Sept. 1941	1	—	—	—	15.1	—	
	do	do	do	—	—	Sept. 1943	2	—	—	—	6.40	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	2.30	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	.90	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	2.00	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	—	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	—	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	—	—	
	do	do	do	—	—	Apr. 1952	1.6	—	—	—	1.00	—	
	do	do	do	—	—	Sept. 1961	9.5	—	—	—	.10	—	
	do	do	do	—	—	Sept. 1967	6	—	—	—	3.36	—	
	do	do	do	—	—	Sept. 1969	2	—	—	—	16.30	—	
70-50c	Nichols Debris Basin	Nichols Canyon	Hollywood, Calif.	.94	.94	Sept. 1942	5	1/—	—	—	2/3.16	—	CE
	do	do	do	—	—	Sept. 1943	1	—	—	—	1.90	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	.68	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	.80	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	.15	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	3.70	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	.29	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	.30	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	.80	—	
	do	do	do	—	—	Apr. 1952	1.6	—	—	—	5.60	—	
	do	do	do	—	—	Feb. 1956	3.8	—	—	—	.67	—	
	do	do	do	—	—	Sept. 1959	3.6	—	—	—	1.39	—	
	do	do	do	—	—	Sept. 1960	1	—	—	—	3.39	—	
	do	do	do	—	—	Sept. 1966	6	—	—	—	1.06	—	
	do	do	do	—	—	Sept. 1968	2	—	—	—	2.15	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	2.97	—	

70-51b	Paradise Debris Basin	Paradise Canyon	La Canada, Calif.	.96	.96	Sept. 1945	1	[1]--	--	--	[2]1.18	--	CE
	do	do	do	--	--	Sept. 1946	1	--	--	--	.92	--	
	do	do	do	--	--	Sept. 1947	1	--	--	--	1.00	--	
	do	do	do	--	--	Sept. 1948	1	--	--	--	.14	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	.10	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	.58	.58	Apr. 1952	1.4	--	--	--	5.38	--	
	do	do	do	--	--	Mar. 1956	3.9	--	--	--	.98	--	
70-52c	Pickens Debris Basin	Pickens Canyon	La Crescenta, Calif.	1.84	1.84	Sept. 1936	1	[1]--	--	--	[2]11.0	--	CE
	do	do	do	--	--	Sept. 1937	1	--	--	--	6.89	--	
	do	do	do	--	--	Sept. 1938	1	--	--	--	44.9	--	
	do	do	do	--	--	Sept. 1939	1	--	--	--	2.95	--	
	do	do	do	--	--	Sept. 1940	1	--	--	--	4.75	--	
	do	do	do	--	--	Sept. 1941	1	--	--	--	11.6	--	
	do	do	do	--	--	Sept. 1943	2	--	--	--	9.03	--	
	do	do	do	--	--	Sept. 1944	1	--	--	--	3.00	--	
	do	do	do	--	--	Sept. 1945	1	--	--	--	.51	--	
	do	do	do	--	--	Sept. 1946	1	--	--	--	.23	--	
	do	do	do	--	--	Sept. 1947	1	--	--	--	.37	--	
	do	do	do	--	--	Sept. 1948	1	--	--	--	.15	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1952	2	--	--	--	2.25	--	
	do	do	do	--	--	Sept. 1959	7	--	--	--	2.81	--	
	do	do	do	--	--	Sept. 1966	7	--	--	--	3.41	--	
	do	do	do	--	--	Sept. 1970	4	--	--	--	4.44	--	
70-53c	Rubio Debris Dam	Rubio Wash	Altadena, Calif.	1.3	1.3	Sept. 1946	3	[1]--	--	--	[2].69	--	CE
	do	do	do	--	--	Sept. 1947	1	--	--	--	.32	--	
	do	do	do	--	--	Sept. 1948	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1952	2	--	--	--	1.23	--	
	do	do	do	--	--	Apr. 1957	4.7	--	--	--	.05	--	
	do	do	do	--	--	Sept. 1966	9.4	--	--	--	2.07	--	
	do	do	do	--	--	Sept. 1969	3	--	--	--	10.0	--	
70-54b	Scholl Debris Basin	Scholl Canyon	Glendale, Calif.	.66	.66	Sept. 1947	2	[1]--	--	--	[2].32	--	CE
	do	do	do	--	--	Sept. 1948	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1952	2	--	--	--	1.45	--	
	do	do	do	--	--	Sept. 1961	9	--	--	--	.53	--	
	do	do	do	--	--	Sept. 1970	9	--	--	--	.88	--	
70-55c	Shields Debris Basin	Shields Channel	La Crescenta, Calif.	.27	.27	Sept. 1938	1	[1]--	--	--	[2]77.0	--	CE
	do	do	do	--	--	Sept. 1939	1	--	--	--	10.1	--	
	do	do	do	--	--	Sept. 1941	2	--	--	--	10.9	--	
	do	do	do	--	--	Sept. 1943	2	--	--	--	5.85	--	
	do	do	do	--	--	Sept. 1944	1	--	--	--	2.33	--	
	do	do	do	--	--	Sept. 1945	1	--	--	--	.52	--	
	do	do	do	--	--	Sept. 1946	1	--	--	--	1.04	--	
	do	do	do	--	--	Sept. 1947	1	--	--	--	.04	--	
	do	do	do	--	--	Sept. 1948	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1952	1.5	--	--	--	10.9	--	
	do	do	do	--	--	Sept. 1961	9.5	--	--	--	2.07	--	
	do	do	do	--	--	Sept. 1966	5	--	--	--	6.81	--	
70-56c	Snover Debris Basin	Snover Canyon	do	.23	.23	Sept. 1938	2	[1]--	--	--	[2]22.6	--	CE
	do	do	do	--	--	Sept. 1939	1	--	--	--	57.0	--	
	do	do	do	--	--	Sept. 1941	2	--	--	--	4.4	--	
	do	do	do	--	--	Sept. 1943	2	--	--	--	8.30	--	
	do	do	do	--	--	Sept. 1945	2	--	--	--	.65	--	
	do	do	do	--	--	Sept. 1952	7	--	--	--	1.09	--	
	do	do	do	--	--	Sept. 1961	9	--	--	--	.06	--	
	do	do	do	--	--	Sept. 1968	7	--	--	--	3.30	--	
	do	do	do	--	--	Sept. 1969	1	--	--	--	56.5	--	
70-57b	Sparr Debris Basin	Sparr Channel	Montrose, Calif.	.84	.84	Sept. 1947	.6	[1]--	--	--	[2]0	--	CE
	do	do	do	--	--	Sept. 1948	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1949	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	1	--	--	--	0	--	
	do	do	do	--	--	Mar. 1952	1.5	--	--	--	3.56	--	
	do	do	do	--	--	Feb. 1956	3.9	--	--	--	1.13	--	
70-58b	Stough Debris Basin	Stough Canyon Channel	Burbank, Calif.	1.65	1.65	Sept. 1943	3	[1]--	--	--	[2]4.22	--	CE
	do	do	do	--	--	Sept. 1944	1	--	--	--	2.84	--	
	do	do	do	--	--	Sept. 1945	1	--	--	--	1.76	--	
	do	do	do	--	--	Sept. 1946	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1947	1	--	--	--	0	--	
	do	do	do	--	--	Sept. 1950	3	--	--	--	0	--	
	do	do	do	--	--	Apr. 1952	1.6	--	--	--	2.73	--	
	do	do	do	--	--	Sept. 1958	6.4	--	--	--	.37	--	
	do	do	do	--	--	Sept. 1960	2.0	--	--	--	.75	--	

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[1] Capacity of debris basin varies. Debris excavated at various times.

[2] Sedimentation values as computed by LACFCD are based on complete water year.

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SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
70-59a	Sunset Canyon Debris Bas (upper)	Sunset Canyon Channel	Burbank, Calif.	0.44	0.44	Sept. 1942	13	1/—	—	—	2/1.34	—	CE
	do	do	do	—	—	Sept. 1944	2	—	—	—	.84	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	.18	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	.20	—	
	do	do	do	—	—	Sept. 1950	4	—	—	—	0	—	
	do	do	do	—	—	Sept. 1952	2	—	—	—	2.41	—	
	do	do	do	—	—	Sept. 1959	7	—	—	—	1.68	—	
	do	do	do	—	—	Sept. 1966	7	—	—	—	7.80	—	
	do	do	do	—	—	Sept. 1969	3	—	—	—	6.20	—	
70-60	Vanalden Debris Basin	Vanalden Channel	Encino, Calif.	1.08	1.08	Sept. 1946	1	1/—	—	—	2/.32	—	CE
	do	do	do	—	—	Sept. 1947	1	—	—	—	.02	—	
	do	do	do	—	—	Sept. 1950	3	—	—	—	—	—	
70-61a	Verdugo Debris Basin	Verdugo Wash	Montrose, Calif.	15.5	10.0	Sept. 1938	3.58	1/—	—	—	2/1.03	—	CE
	do	do	do	—	—	Sept. 1941	3	—	—	—	.81	—	
	do	do	do	—	—	Sept. 1943	2	—	—	—	2.05	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	4.27	—	
	do	do	do	—	—	Sept. 1950	6	—	—	—	.06	—	
	do	do	do	—	—	Sept. 1952	2	—	—	—	.82	—	
	do	do	do	—	—	Sept. 1953	1	—	—	—	3.73	—	
	do	do	do	—	—	May 1956	2.67	—	—	—	.002	—	
	do	do	do	—	—	Jan. 1959	2.67	—	—	—	.09	—	
	do	do	do	—	—	Sept. 1960	1.66	—	—	—	.05	—	
	do	do	do	—	—	Sept. 1964	4	—	—	—	.57	—	
	do	do	do	—	—	Sept. 1966	2	—	—	—	1.71	—	
	do	do	do	—	—	Sept. 1968	2	—	—	—	.05	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	3.14	—	
70-62b	Ward Debris Basin (Lower)	Ward Canyon	La Crescenta, Calif.	3/.64	3/.64	Sept. 1945	1	1/—	—	—	2/.51	—	CE
	do	do	do	—	—	Sept. 1946	1	—	—	—	1.63	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	4.86	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	1.00	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	.36	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	1.11	—	
	do	do	do	—	—	Feb. 1952	1.3	—	—	—	6.41	—	
	do	do	do	—	—	Apr. 1952	.2	—	—	—	—	—	
	do	do	do	—	—	Sept. 1956	4.4	—	—	—	.52	—	
	do	do	do	—	—	Sept. 1958	2.0	—	—	—	.70	—	
70-63b	West Ravine Debris Basin	West Ravine Canyon	Altadena, Calif.	.25	.25	Sept. 1936	1	1/—	—	—	2/67.05	—	CE
	do	do	do	—	—	Sept. 1937	1	—	—	—	65.42	—	
	do	do	do	—	—	Sept. 1938	1	—	—	—	73.85	—	
	do	do	do	—	—	Sept. 1940	2	—	—	—	3.60	—	
	do	do	do	—	—	Sept. 1941	1	—	—	—	21.4	—	
	do	do	do	—	—	Sept. 1942	1	—	—	—	.44	—	
	do	do	do	—	—	Sept. 1943	1	—	—	—	20.20	—	
	do	do	do	—	—	Sept. 1944	1	—	—	—	8.00	—	
	do	do	do	—	—	Sept. 1945	1	—	—	—	.80	—	
	do	do	do	—	—	Sept. 1946	1	—	—	—	1.56	—	
	do	do	do	—	—	Sept. 1947	1	—	—	—	1.52	—	
	do	do	do	—	—	Sept. 1948	1	—	—	—	.02	—	
	do	do	do	—	—	Sept. 1949	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1950	1	—	—	—	0	—	
	do	do	do	—	—	Sept. 1952	2	—	—	—	4.76	—	
	do	do	do	—	—	Sept. 1964	12	—	—	—	1.88	—	
	do	do	do	—	—	Sept. 1968	4	—	—	—	8.69	—	
	do	do	do	—	—	Sept. 19'	1	—	—	—	43.2	—	
70-64	Camp Marston	Bear Creek	Julian, Calif.	1.6	1.59	— 1918	—	44.1	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	33	36.9	—	90	.14	183.0	
70-65b	Cooks Canyon Debris Basin	Cooks Canyon	La Crescenta, Calif.	.58	.58	Mar. 1952	.2	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1961	9.5	—	—	—	2/.280	—	
	do	do	do	—	—	Sept. 1969	8	—	—	—	.038	—	
70-66	Auburn Debris Basin	Auburn River	Sierra Madre, Calif.	.19	.19	Dec. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	4.8	—	—	—	2.6	—	
70-67a	Bradbury Debris Basin	Bradbury Canyon	Monrovia, Calif.	.68	.68	Jan. 1955	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	4.67	—	—	—	2/8.15	—	
	do	do	do	—	—	Sept. 1961	2.0	—	—	—	1.62	—	
	do	do	do	—	—	Sept. 1966	5	—	—	—	6.65	—	
	do	do	do	—	—	Sept. 1969	3	—	—	—	23.5	—	

70-68a	Carter Debris Basin	Carter Canyon	Sierra Madre, Calif.	.12	.12	Dec. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	4.8	—	—	—	2/2.8	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	23.7	—	
	do	do	do	—	—	Sept. 1969	7	—	—	—	4.05	—	
70-69a	Bear Debris Basin	Bear Canyon	Glendale, Calif.	.59	.59	Jan. 1955	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	4.83	—	—	—	2/.55	—	
	do	do	do	—	—	Sept. 1964	5	—	—	—	2.10	—	
	do	do	do	—	—	Sept. 1965	1	—	—	—	24.74	—	
	do	do	do	—	—	Sept. 1966	1	—	—	—	21.19	—	
	do	do	do	—	—	Sept. 1969	3	—	—	—	19.0	—	
70-70	Floral (Upper) Debris Basin	Floral Canyon	Sierra Madre, Calif.	.06	.06	Mar. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	5.6	—	—	—	2.6	—	
70-71	La Tuna Debris Basin	La Tuna Canyon	Los Angeles, Calif.	5.34	5.34	Jan. 1956	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Feb. 1956	.1	—	—	—	—	—	
	do	do	do	—	—	July 1957	1.4	—	—	—	2/.04	—	
	do	do	do	—	—	Sept. 1958	1.2	—	—	—	.13	—	
	do	do	do	—	—	Sept. 1959	1.0	—	—	—	2.15	—	
	do	do	do	—	—	Sept. 1960	1.0	—	—	—	1.22	—	
70-72a	Lannan Debris Basin	Lannan Wash	Sierra Madre, Calif.	.25	.25	Mar. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	5.6	—	—	—	2/5.44	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	11.3	—	
	do	do	do	—	—	Sept. 1967	5	—	—	—	.48	—	
	do	do	do	—	—	Sept. 1970	3	—	—	—	20.4	—	
70-73b	Maddock Debris Basin	Maddock Canyon	Duarte, Calif.	.25	.25	Jan. 1955	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Mar. 1956	1.2	—	—	—	2/17.8	—	
	do	do	do	—	—	Sept. 1959	3.5	—	—	—	3.88	—	
	do	do	do	—	—	Sept. 1967	8.0	—	—	—	1.8	—	
	do	do	do	—	—	Sept. 1969	2	—	—	—	15.8	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	2.96	—	
70-74a	May No. 1 Debris Basin	May Canyon	San Fernando, Calif.	.70	.70	Aug. 1953	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	6.2	—	—	—	2/.78	—	
	do	do	do	—	—	Sept. 1967	8	—	—	—	7.20	—	
	do	do	do	—	—	Sept. 1968	1	—	—	—	23.3	—	
	do	do	do	—	—	Sept. 1969	1	—	—	—	104.0	—	
70-75a	May No. 2 Debris Basin	do	do	.09	.09	Aug. 1953	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	6.2	—	—	—	2/.36	—	
	do	do	do	—	—	Sept. 1967	8	—	—	—	11.9	—	
	do	do	do	—	—	Sept. 1968	1	—	—	—	45.5	—	
	do	do	do	—	—	Sept. 1969	1	—	—	—	28.9	—	
70-76a	McClure Debris Basin	McClure Canyon	Burbank, Calif.	.62	.62	Dec. 1953	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	5.8	—	—	—	2/5.6	—	
	do	do	do	—	—	Sept. 1961	2.0	—	—	—	9.27	—	
	do	do	do	—	—	Sept. 1965	4	—	—	—	2.9	—	
	do	do	do	—	—	Sept. 1966	1	—	—	—	10.0	—	
	do	do	do	—	—	Sept. 1967	1	—	—	—	9.52	—	
70-77	Rowley Debris Basin	Rowley Canyon	Tujunga, Calif.	.58	.58	Jan. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	5.67	—	—	—	2/.62	—	
	do	do	do	—	—	Sept. 1968	9	—	—	—	1.5	—	
	do	do	do	—	—	Sept. 1969	1	—	—	—	11.8	—	
70-78	Ruby - Upper Debris Basin	Ruby Canyon	Sierra Madre, Calif.	.21	.21	Jan. 1954	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	5.8	—	—	—	2/5.2	—	
	do	do	do	—	—	Sept. 1961	2.0	—	—	—	.29	—	
70-79a	Ruby - Lower Debris Basin	do	do	.10	.10	Dec. 1955	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	3.8	—	—	—	2/2.9	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	1.0	—	
	do	do	do	—	—	Sept. 1969	7	—	—	—	12.8	—	
70-80a	Sawpit Debris Dam	Sawpit Creek	Monrovia, Calif.	6.34	2.84	Jan. 1955	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	4.67	—	—	—	2/4.6	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	6.9	—	
	do	do	do	—	—	Sept. 1969	7	—	—	—	9.82	—	
70-81a	Sierra Madre Villa Debris Basin.	Sierra Madre Villa Canyon	Sierra Madre, Calif.	1.46	1.46	May 1958	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	1.4	—	—	—	2/.34	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	16.92	—	
	do	do	do	—	—	Sept. 1968	6	—	—	—	.18	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	45.89	—	
70-82a	Spinks Debris Basin	Spinks Canyon	Monrovia, Calif.	.44	.44	Dec. 1958	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	.8	—	—	—	2/—	—	
	do	do	do	—	—	Sept. 1962	3	—	—	—	1.66	—	
	do	do	do	—	—	Sept. 1969	7	—	—	—	5.32	—	
70-83a	Turnbull Debris Basin	Turnbull Canyon Wash	Whittier, Calif.	.99	.99	Jan. 1953	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	6.8	—	—	—	2/.28	—	
	do	do	do	—	—	Sept. 1968	9	—	—	—	1.33	—	
	do	do	do	—	—	Sept. 1969	1	—	—	—	16.0	—	
70-84a	Zachau Debris Basin	Zachau Canyon	Tujunga, Calif.	.35	.35	Aug. 1956	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1959	3.2	—	—	—	2/.80	—	
	do	do	do	—	—	Sept. 1961	2.0	—	—	—	.80	—	
	do	do	do	—	—	Sept. 1969	8	—	—	—	2.37	—	

1/ Capacity of debris basin varies. Debris excavated at various times.
2/ Sedimentation values computed by Los Angeles County FCD are based on complete wateryear.
3/ Drainage area 0.35 sq. mi. through 1967; 0.44 after 1967.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	SALTON SEA AND SOUTHERN CALIFORNIA COASTAL AND GREAT BASIN DRAINAGE (Continued)												
70-83a	Ward Debris Basin (Upper)	Ward Canyon	La Crescenta, Calif.	0.10	0.10	Nov. 1956	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1957	.8	—	—	—	2/30.1	—	
	do	do	do	—	—	Sept. 1958	1.0	—	—	—	39.3	—	
	do	do	do	—	—	Sept. 1959	1.0	—	—	—	17.5	—	
	do	do	do	—	—	Sept. 1967	8	—	—	—	.4	—	
	do	do	do	—	—	Sept. 1968	1	—	—	—	3.1	—	
	do	do	do	—	—	Sept. 1969	1	—	—	—	22.9	—	
70-86	Sepulveda Flood Control Basin	Los Angeles River	Van Nuys, Calif.	152	142	Nov. 1941	—	16,720	1.00	—	—	—	CE
	do	do	do	—	—	Nov. 1944	3.0	17,437	1.04	—	—	—	
	do	do	do	—	—	June 1961	16.6	17,296	1.03	—	.06	—	
70-87a	Santa Fe Flood Control Basin	San Gabriel River	Baldwin Park, Calif.	236.0	3/20.54	Apr. 1943	—	34,670	—	—	—	—	CE
	do	do	do	—	—	Nov. 1949	6.6	34,276	—	—	2.91	—	
	do	do	do	—	—	Mar. 1959	9.3	33,987	—	—	1.51	—	
	do	do	do	—	—	June 1961	2.2	33,385	—	—	13.32	—	
	do	do	do	—	—	Feb. 1967	5.7	32,716	—	—	5.72	—	
	do	do	do	—	—	Sept. 1968	1.6	1/34,916	—	—	—	—	
	do	do	do	—	—	Aug. 1969	.9	32,642	—	—	123.0	—	
70-88a	Bell IV (080A)	Bell Creek	Glendora, Calif.	.061	.061	Jan. 1966	—	2.30	.234	—	—	—	FS
	do	do	do	—	—	Dec. 1966	.96	—	—	—	1.16	—	
	do	do	do	—	—	Oct. 1968	1.86	—	—	—	0	—	
	do	do	do	—	—	Mar. 1969	.43	—	—	—	39.6	—	
	do	do	do	—	—	July 1970	1.41	—	—	—	.018	—	
70-89	Bell Debris Basin	do	Canoga Park, Calif.	7.0	7.0	— —	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1970	3	—	—	—	2/.71	—	
70-90	Carbon Canyon F. C. Basin	Carbon Canyon Creek	Brea, Calif.	19.3	19.3	Mar. 1961	—	7,033	10.0	—	—	—	CE
	do	do	do	—	—	Sept. 1969	8.5	6,615	9.45	—	2.54	—	
70-91	Childs Debris Basin	Childs Canyon	Glendale, Calif.	.31	.31	Sept. 1963	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1966	3	—	—	—	2/8.81	—	
70-92	Elmwood Debris Basin	Elmwood Canyon	Burbank, Calif.	.31	.31	— 1964	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1968	4	—	—	—	2/7.90	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	.10	—	
70-93	Eaglewild Debris Basin	Eaglewild Canyon	Glendora, Calif.	.4	.4	Sept. 1961	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1969	8	—	—	—	2/10.4	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	13.5	—	
70-94	Harrow Debris Basin	Harrow Canyon	Glendora, Calif.	.43	.43	Sept. 1958	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1969	11	—	—	—	2/6.77	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	16.3	—	
70-95	Rock Rest Debris Basin	Rock Canyon	Azusa, Calif.	.18	.18	Sept. 1967	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1969	2	—	—	—	2/66.7	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	2.78	—	
70-96	Kinneloa Debris Basin	Kinneloa Canyon	Pasadena, Calif.	.20	.20	Oct. 1964	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1966	1.92	—	—	—	2/10.90	—	
	do	do	do	—	—	Sept. 1969	3	—	—	—	21.65	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	12.70	—	
70-97	Kinneloa - West Debris Basin	do	Altadena, Calif.	.16	.16	Sept. 1966	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1969	3	—	—	—	2/30.8	—	
	do	do	do	—	—	Sept. 1970	1	—	—	—	19.4	—	
70-98	Little Dalton Debris Basin	Little Dalton	Glendora, Calif.	3.3	3.3	Feb. 1960	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1962	2.6	—	—	—	2/15.7	—	
	do	do	do	—	—	Sept. 1969	7	—	—	—	12.4	—	
70-99	Morgan Debris Basin	Morgan Canyon	do	.6	.6	Sept. 1964	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1969	5	—	—	—	2/2.95	—	
70-100	San Antonio F. C. Basin	San Antonio Creek	Claremont, Calif.	26.7	26.7	Aug. 1956	—	9,385	.90	—	—	—	CE
	do	do	do	—	—	July 1969	12.92	6,718	.65	—	7.65	—	
70-101	Schoolhouse Debris Basin	Mansfield Av. Storm Drain	Olive View, Calif.	.28	.28	June 1963	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1967	4.2	—	—	—	2/11.1	—	
70-102	Sunset Debris Basin (Lower)	Sunset Canyon	Glendale, Calif.	.65	.65	Jan. 1965	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1967	2.7	—	—	—	2/5.58	—	
70-103	Santa Anita Debris Basin	Santa Anita Creek	Arcadia, Calif.	1.7	1.7	Dec. 1959	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1962	2.8	—	—	—	2/19.1	—	
	do	do	do	—	—	Sept. 1968	6	—	—	—	.67	—	
	do	do	do	—	—	Sept. 1970	2	—	—	—	50.0	—	
70-104	Wilson Debris Basin	Wilson Canyon	Olive View, Calif.	2.58	2.58	June 1963	—	1/—	—	—	—	—	CE
	do	do	do	—	—	Sept. 1967	4.2	—	—	—	2/5.23	—	

70-105	Wildwood Debris Basin	Wildwood Creek	Newhall, Calif.	.65	.65	Sept. 1967	--	1/--	--	—	—	—	CE
	do	do	do	—	—	Sept. 1969	2	—	—	—	2/9.85	—	
70-106	Winery Debris Basin	Winery Canyon	La Crescenta, Calif.	.18	.18	Sept. 1968	--	1/--	—	—	--	—	CE
	do	do	do	—	—	Sept. 1969	1	—	—	—	2/28.2	—	
			SAN JOAQUIN AND KERN RIVER BASINS AND ADJACENT COASTAL DRAINAGE										
71-1	Upper Crystal Springs	Laguna Creek	San Francisco, Calif.	13.3	12.0	Jan. 1870	—	29,130	12.67	—	—	—	SCS
	do	do	do	—	—	Oct. 1935	57.8	28,159	12.24	—	1.41	—	
71-2	Atascadero Park Lake	Atascadero Creek	Atascadero, Calif.	1.0	1.0	— 1918	—	150	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1947	29	136	—	*60	.48	627	
71-3	Hawkins	N. Fk. Los Viboras Creek	Hollister, Calif.	4.04	4.01	— 1912	--	549	—	—	—	—	SCS
	do	do	do	—	—	May 1940	28	4/532	—	*60	4/.15	196	
71-4a	Salinas	Salinas River	Santa Margarita, Calif.	111	110	— 1942	—	26,000	—	—	—	—	SCS
	do	do	do	—	—	Nov. 1947	6	25,860	—	—	.21	—	
	do	do	do	--	—	Aug. 1953	6	25,590	—	60	.41	357	
71-5	Copperopolis	Penney Creek	Copperopolis, Calif.	2.06	2.01	— 1913	—	265	—	—	—	—	SCS
	do	do	do	--	--	Aug. 1945	30	263	—	55	.034	40.7	
71-6	Crane Valley	N. Fk. San Joaquin River	Madera, Calif.	54.5	52.7	— 1901	—	45,410	—	—	—	--	SCS
	do	do	do	—	—	June 1946	45	45,020	—	*62	.161	217	
71-7	Davis	Shaw Creek	Stockton, Calif.	7.87	7.62	— 1917	—	1,421	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1945	28	1,367	—	63	.251	344	
71-8	Don Pedro	Tuolumne River	Modesto, Calif.	1,001	996.5	Mar. 1923	—	289,000	—	--	—	—	SCS
	do	do	do	—	—	Nov. 1945	22.7	284,266	—	*62	.210	284	
71-9	Exchequer	Merced River	Merced, Calif.	1,027	1,022.4	Sept. 1926	—	281,000	—	--	—	—	SCS
	do	do	do	—	—	Mar. 1946	19.6	265,646	—	62	.167	226	
71-10	Oilmore	Trib. of Mormon Slough	Bellota, Calif.	5.01	4.92	Sept. 1917	—	579	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1945	28	560	—	90	.132	144	
71-11	Hume	Ten Mile Creek	Fresno, Calif.	24.2	24.1	June 1909	—	1,410	—	—	—	—	SCS
	do	do	do	—	—	June 1946	37.0	1,383	—	*62	.090	40.5	
71-12	La Grange	Tuolumne River	Modesto, Calif.	1,501	5/1,501	Sept. 1893	—	2,332	—	—	—	—	SCS
	do	do	do	--	—	Oct. 1905	10.1	1,068	--	*70	.083	127	
71-13	Lyons	S. Fk. Stanislaus River	Tuolumne, Calif.	6/40.0	39.7	June 1930	—	5,500	—	—	—	—	SCS
	do	do	do	--	—	June 1946	16	5,436	—	*70	.101	154	
71-14	McCarty	Trib. of Johnny Creek	San Andreas, Calif.	.35	.32	Dec. 1937	—	96.3	—	—	—	—	SCS
	do	do	do	--	—	Sept. 1945	7.7	95.5	—	*45	.300	296	
71-15	Pardee	Mokelumne River	Lodi, Calif.	7/387	383.5	— 1929	—	210,000	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1943	14	209,183	—	*62	.152	205	
71-16	Salt Springs Valley	Rock Creek	San Andreas, Calif.	20.3	18.4	— 1882	—	12,950	—	—	—	—	SCS
	do	do	do	—	—	July 1945	63	12,697	—	*50	.201	219	
71-17	(Upper) Bear River	Bear River	Placerville, Calif.	28.5	28.2	Sept. 1900	—	8,712	—	—	--	—	SCS
	do	do	do	—	—	June 1946	45.8	8,690	—	*70	.017	26	
71-18a	Woods Pond	Sycamore Creek	Danville, Calif.	.30	.30	— 1940	—	4.41	—	—	—	—	SCS
	do	do	do	—	—	— 1951	11	4.23	—	80	.053	92.3	
71-19	St. Mary's	Walnut Creek	Walnut Creek, Calif.	3.11	2.97	— 1928	—	134.01	—	—	—	—	SCS
	do	do	do	—	—	— 1951	23	88.59	—	65	.66	667	
71-20	Black Hills	Green Valley Creek	Danville, Calif.	.76	.76	— 1880	—	32.68	—	—	—	—	SCS
	do	do	do	—	—	— 1951	71	27.04	—	66	.11	110.2	
71-21	Lakewood	Walnut Creek	Concord, Calif.	.75	.74	— 1913	—	27.08	—	—	—	—	SCS
	do	do	do	--	—	— 1951	40	24.86	—	30	.076	69.66	
71-22	Contra Costa Country Club	Grayson Creek	Pacheco, Calif.	.20	.20	-- 1934	—	5.75	—	—	—	—	SCS
	do	do	do	--	—	— 1951	17	5.24	—	40	.15	131	
71-23	Englehart Pond	Marsh Creek	Brentwood, Calif.	.033	.033	— 1945	—	1.34	—	—	—	—	SCS
	do	do	do	—	—	Jan. 1953	7	1.32	—	*60	.088	115	
71-24a	C. C. Anderson Pond	do	do	.083	.083	— 1945	—	1.920	--	—	—	—	SCS
	do	do	do	--	—	Oct. 1952	7	1.864	--	*65	8/.096	8/136	
71-25	Upper Walter Keller Pond	do	do	.027	.027	— 1943	—	1.347	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1952	9	1.185	—	*60	8/.682	8/596	
71-26	P. J. Rosy Pond	Alhambra Creek	do	.045	.045	— 1947	—	2.45	—	—	—	--	SCS
	do	do	do	--	—	Jan. 1953	5	2.32	—	*55	8/.578	8/692.38	
71-27a	Lee Higgins Pond	Marsh Creek	do	.202	.199	— 1941	—	12.60	—	—	—	—	SCS
	do	do	do	--	—	Oct. 1953	12	12.28	—	*60	.14	122	
71-28a	Souza	do	do	.319	.285	— 1946	—	176.49	—	—	—	—	SCS
	do	do	do	—	—	Jan. 1953	6	174.97	—	*30	.096	984	
71-29a	Ordway	do	do	.619	.613	— 1945	—	60.9	--	—	—	—	SCS
	do	do	do	—	—	Jan. 1953	7	60.07	—	*70	.19	290	
71-30	North Fork	Pacheco Creek	Hollister, Calif.	66.2	66.0	— 1938	—	5,803	—	—	—	—	SCS
	do	do	do	—	—	Apr. 1951	12.4	5,706	—	*65	8/.12	8/117.61	

1/ Capacity of debris basin varies. Debris excavated at various times.
2/ Sedimentation values as computed by Los Angeles County FCD are based on complete water year.
3/ Excludes drainage area above Morris Dam (215.46 sq. mi.).
4/ Some sediment sluiced out incidental to work on outlet.
5/ Before construction of Don Pedro Reservoir in 1923.

6/ Excluding drainage area of Strawberry Reservoir.
7/ Excluding noncontributing areas above Salt Springs and Bear River Reservoirs.
8/ Excluding pond area.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	SAN JOAQUIN AND KERN RIVER BASINS AND ADJACENT COASTAL DRAINAGE (Continued)												
71-31a	Teakettle Reservoir No. 1	Teakettle Creek	Fresno, Calif.	0.77	0.77	Fall 1938	—	0.39	—	—	—	—	FS
	do	do	do	—	—	Fall 1948	10.0	.18	—	—	0.0271	—	
	do	do	do	—	—	Fall 1951	3.0	.002	—	—	.1100	—	
	do	do	do	—	—	Fall 1955	4.0	0	—	—	.0078	—	
	do	do	do	—	—	Fall 1956	—	1/.352	—	—	—	—	
	do	do	do	—	—	Fall 1957	1.0	—	—	—	—	—	
	do	do	do	—	—	Fall 1958	1.0	—	—	—	.0391	—	
	do	do	do	—	—	Fall 1959	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1960	1.0	—	—	—	.7858	—	
	do	do	do	—	—	Fall 1961	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1962	1.0	—	—	—	.0065	—	
	do	do	do	—	—	Fall 1963	1.0	—	—	—	.3228	—	
	do	do	do	—	—	Fall 1964	1.0	—	—	—	.0889	—	
	do	do	do	—	—	Fall 1965	1.0	—	—	—	.0054	—	
71-32a	Teakettle Reservoir No. 2a	do	do	.273	.273	Fall 1938	—	.079	—	—	—	—	FS
	do	do	do	—	—	Fall 1941	3.0	.068	—	—	.0146	—	
	do	do	do	—	—	Fall 1948	7.0	.050	—	—	.0084	—	
	do	do	do	—	—	Fall 1951	3.0	.030	—	—	.0280	—	
	do	do	do	—	—	Fall 1955	4.0	.015	—	—	.0110	—	
	do	do	do	—	—	Fall 1956	1.0	2/.066	—	—	—	—	
	do	do	do	—	—	Fall 1957	1.0	—	—	—	—	—	
	do	do	do	—	—	Fall 1958	1.0	—	—	—	.0241	—	
	do	do	do	—	—	Fall 1959	1.0	—	—	—	.0059	—	
	do	do	do	—	—	Fall 1960	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1961	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1962	1.0	—	—	—	.0003	—	
	do	do	do	—	—	Fall 1963	1.0	—	—	—	.0462	—	
	do	do	do	—	—	Fall 1964	1.0	—	—	—	.0572	—	
	do	do	do	—	—	Fall 1965	1.0	—	—	—	0	—	
71-33a	Teakettle Reservoir No. 2	do	do	.847	.847	Fall 1938	—	.134	—	—	—	—	FS
	do	do	do	—	—	Fall 1948	10.0	.098	—	—	.0066	—	
	do	do	do	—	—	Fall 1952	3.0	.021	—	—	.0290	—	
	do	do	do	—	—	Fall 1955	4.0	.0022	—	—	.0080	—	
	do	do	do	—	—	Fall 1956	—	2/.101	—	—	—	—	
	do	do	do	—	—	Fall 1957	1.0	—	—	—	—	—	
	do	do	do	—	—	Fall 1958	1.0	—	—	—	.0166	—	
	do	do	do	—	—	Fall 1959	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1960	1.0	—	—	—	.0032	—	
	do	do	do	—	—	Fall 1961	1.0	—	—	—	.0032	—	
	do	do	do	—	—	Fall 1962	1.0	—	—	—	.0015	—	
	do	do	do	—	—	Fall 1963	1.0	—	—	—	.0474	—	
	do	do	do	—	—	Fall 1964	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1965	1.0	—	—	—	—	—	
71-34a	Teakettle Reservoir No. 3	do	do	.856	.856	Fall 1938	—	.131	—	—	—	—	FS
	do	do	do	—	—	Fall 1940	2.0	.127	—	—	.0026	—	
	do	do	do	—	—	Fall 1941	1.0	.109	—	—	.0804	—	
	do	do	do	—	—	Fall 1948	7.0	.060	—	—	.0112	—	
	do	do	do	—	—	Fall 1951 3/	3.0	.007	—	—	.0160	—	
	do	do	do	—	—	Fall 1956	—	3/.117	—	—	—	—	
	do	do	do	—	—	Fall 19.	1.0	—	—	—	—	—	
	do	do	do	—	—	Fall 1958	1.0	—	—	—	.0073	—	
	do	do	do	—	—	Fall 1959	1.0	—	—	—	.0042	—	
	do	do	do	—	—	Fall 1960	1.0	—	—	—	.0003	—	
	do	do	do	—	—	Fall 1961	1.0	—	—	—	0	—	
	do	do	do	—	—	Fall 1962	1.0	—	—	—	.0049	—	
	do	do	do	—	—	Fall 1963	1.0	—	—	—	.1457	—	
	do	do	do	—	—	Fall 1964	1.0	—	—	—	.0619	—	
	do	do	do	—	—	Fall 1965	1.0	—	—	—	.0338	—	
71-35	Teakettle No. 7	do	do	.091	.091	Fall 1956	(1938-56)	.222	.159	—	—	—	FS
	do	do	do	—	—	Fall 1957	19.0	.181	.129	—	.029	—	
	do	do	do	—	—	Fall 1958	1.0	.178	.127	—	4/-.013	—	
	do	do	do	—	—	Fall 1959	1.0	.182	.130	—	4/-.037	—	
	do	do	do	—	—	Fall 1960	1.0	.178	.127	—	.068	—	

71-36	Pine Flat	Kings River	Sanger, Calif.	1,542	1,542	May	1952	--	1,013,400	.612	--	--	--	CE
	do	do	do	--	--	Feb.	1954	5/1.8	1,013,290	.612	*62	.04	54	
	do	do	do	--	--	Nov.	1956	5/3	1,011,950	.611	*62	.29	392	
71-37	Salinas Boys Ranch	Trib. of Natividad Creek	Salinas, Calif.	.13	.13	Oct.	1953 7/	--	7/9.65	--	--	--	--	SCS
	do	do	do	--	--	Sept.	1964	11	9.34	--	*65	.23	325.6	
71-38	Roy Alexander	do	do	.205	.203	--	1951 8/	--	8/8.40	--	--	--	--	SCS
	do	do	do	--	--	Sept.	1964	13	8.15	--	*65	.10	141.6	
71-39	Gibralter	Santa Inez	Santa Barbara, Calif.	216	6/202.2	Oct.	1919	--	15,296	.42	--	--	--	GS
	do	do	do	--	--	Aug.	1923	3.83	13,674	.38	--	1.96	--	
	do	do	do	--	--	Aug.	1944	21	7,720	.21	--	9/1.47	--	
	do	do	do	--	--	Feb.	1956	11.42	14,777	.41	--	.43	--	
	do	do	do	--	--	Aug.	1969	13.5	9,654	.27	--	1.88	--	
71-40	Santa Felicia	Piru Creek	Piru, Calif.	425	425	Oct.	1955	--	101,200	--	--	--	--	GS
	do	do	do	--	--	Oct.	1965	10	98,730	--	52	.98	658	
71-41	Success Lake	Tule River	Porterville, Calif.	393	393	Sept.	1960	--	*86,160	.681	--	--	--	CE
	do	do	do	--	--	Nov.	1965	5.2	86,160	.681	--	*0	*0	
	do	do	do	--	--	Nov.	1967	2.0	83,610	.660	*62	3.244	4,383	
	do	do	do	--	--	Dec.	1968	1.1	83,680	.661	*62	-.163	-218.7	
71-42	Isabella Reservoir	Kern River	Isabella, Calif.	2,074	2,074	June	1953	--	539,665	.81	--	--	--	CE
	do	do	do	--	--	Sept.	1956	3.3	539,115	.81	*62	.074	100	
	do	do	do	--	--	Dec.	1968	12.2	534,465	.803	*62	.186	252	
71-43	Lake Kaweah (Terminus Dam)	Kaweah River	Lemon Cove, Calif.	560	560	Nov.	1961	--	149,599	.389	--	--	--	CE
	do	do	do	--	--	Nov.	1967	6	147,099	.382	*62	.745	1,006	
71-44	Cachuma	Santa Inez River	Santa Inez, Calif.	417	196	Jan.	1953	--	204,874	--	--	--	--	BR
	do	do	do	--	--	Aug.	1969	16.58	12/192,574	--	--	10/3.79	--	

SACRAMENTO, EEL AND RUSSIAN RIVER BASINS

72-1a	Ridgewood (Walker)	Walker Creek	Willits, Calif.	5.7	5.6	--	1930	--	313	.10	--	--	--	SCS
	do	do	do	--	--	June	1966	36	218	.07	77.5	.48	1,063	
72-2a	Morris	Davis Creek	do	5.1	5.03	--	1924	--	*320	.12	--	--	--	SCS
	do	do	do	--	--	--	1927	3	*771	.29	--	--	--	
	do	do	do	--	--	May	1960	36	660	.24	*50	.63	686	
	do	do	do	--	--	May	1966	6	643	.24	50.3	.56	642	
72-3	Big Canyon	Big Canyon Creek	French Town, Calif.	5.50	5.48	Nov.	1934	--	200	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1945	11	196	--	44.7	.069	67.2	
72-4	Blodgett	Trib. of Cosumnes River	Sacramento, Calif.	3.12	3.05	Mar.	1940	--	258	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1945	5.6	254	--	45	.217	217	
72-5	Bullards Bar	North Yuba River	Camptonville, Calif.	480	479	Oct.	1919	--	31,500	--	--	--	--	SCS
	do	do	do	--	--	Jan.	1939	19.2	28,993	--	*70	.284	433	
72-6	Combie (Van Geisen)	Bear River	Auburn, Calif.	130	129	June	1928	--	8,545	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1935	7.3	7,840	--	*70	.749	1,140	
72-7b	East Park	Little Stony Creek	Stonyford, Calif.	11/101.5	98.9	Dec.	1910	--	12/50,900	--	--	--	--	GS
	do	do	do	--	--	Nov.	1962	52	48,940	.80	55	13/.37	13/443	
72-8	Faulke Lake (False Lake)	N. Fk. Jenney Creek	Shasta, Calif.	.71	.68	--	1851	--	130	--	--	--	--	SCS
	do	do	do	--	--	Dec.	1945	94	120	--	54	.147	173	
72-9	Gerber	Trib. of Burch Creek	Corning, Calif.	.31	.28	June	1917	--	190	--	--	--	--	SCS
	do	do	do	--	--	Dec.	1945	28.5	182	--	78.3	.971	1,656	
72-10	Magalia	Little Butte Creek	Chico, Calif.	14/8.23	8.08	Jan.	1918	--	3,718	--	--	--	--	SCS
	do	do	do	--	--	Jan.	1946	28	3,648	--	48.8	.307	326	
72-11b	Stony Gorge	Stony Creek	Elk Creek, Calif.	15/199	197	Nov.	1928	--	16/50,300	--	--	--	--	GS
	do	do	do	--	--	Nov.	1962	34.1	48,160	.29	54	13/.27	13/319	
72-12	Misselbeck	N. Fk. Cottonwood Creek	Redding, Calif.	12.0	11.8	May	1920	--	4,300	--	--	--	--	SCS
	do	do	do	--	--	Dec.	1945	25.5	4,086	--	*75	.711	1,161	
72-13	Lake Pillsbury (Scott Dam)	Eel River	Potter Valley, Calif.	283	284	Dec.	1921	--	94,396	.248	--	--	--	GS
	do	do	do	--	--	May	1959	37.5	86,785	.228	73	.71	1,129	
72-14	Catacoula (Bar 49)	Maxewell Creek	St. Helena, Calif.	.71	.69	--	1953	--	183.0	--	--	--	--	SCS
	do	do	do	--	--	Nov.	1958	5	181.4	--	--	.46	--	
72-15	Milliken	Milliken Creek	Napa, Calif.	10.5	10.4	--	1924	--	2,000	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1958	34	1,988	--	--	.04	--	
72-16a	Onion Creek No. 1	Onion Creek, trib. of Amer. River.	Soda Springs, Calif.	.19	.19	--	1957	--	.114	.039	--	--	--	FS
	do	do	do	--	--	--	1958	1.0	.095	.033	--	.074	--	
	do	do	do	--	--	--	1959	1.0	.097	.033	--	.071	--	
	do	do	do	--	--	--	1960	1.0	.093	.032	--	.024	--	
72-17	Onion Creek No. 2	do	do	.48	.48	--	1957	--	.132	.042	--	--	--	FS
	do	do	do	--	--	--	1958	1.0	.083	.026	--	.1226	--	
	do	do	do	--	--	--	1959	1.0	.081	.026	--	.0004	--	
	do	do	do	--	--	--	1960	1.0	.069	.022	--	.0206	--	
72-18	Onion Creek No. 3	do	do	.65	.65	--	1958	--	.191	.062	--	--	--	FS
	do	do	do	--	--	--	1959	1.0	.205	.067	--	17/.0000	--	
	do	do	do	--	--	--	1960	1.0	.186	.061	--	.0273	--	

1/ Overtopped by sediment, no measurements taken in 1956; sediment removed down to original reservoir bottom.

2/ Sediment removed in summer 1956 - no measurements taken.

3/ Last data for which significant data are available; reservoir inoperative until 1956 when sediment was removed.

4/ Loss of sediment not applicable to watershed as a whole.

5/ Period of abnormal operation. Represents 0.3 year of sediment accumulation behind partially closed gates and 1.5 years of sediment depletion with wide open gates. Sediment value is residue at end of period.

6/ Represents sedimentation for 3 full runoff years because no significant inflow occurred from Oct. 1, 1953, to Feb. 13, 1954, or from Oct. 1, 1956, to Nov. 15, 1956.

7/ Original capacity determined from 1965 survey.

8/ Original capacity determined from 1964 survey.

9/ Effective drainage area prior to 1931 was 216 sq. mi. There after 202.2 sq. mi.

10/ Data at elevation 748 (limit of 8-7-69 survey). Spillway crest elevation 750 ft.

11/ Natural drainage area. Flow diverted into the reservoir from Stony Gorge drainage basin after 1914.

12/ Spillway elevation (flashboard crest elevation 50,900); USGS Water-Supply Paper 1798-F.

13/ Based on the natural drainage area.

14/ Excluding 3 sq. mi. above P. G. & E. Canal.

15/ The natural drainage area less area above East Park Reservoir. Flow diverted from the basin to East Park Reservoir after 1914.

16/ U. S. Bureau of Reclamation capacity curve (3-31-45); USGS Water-Supply Papers 1535 Part II., 1798-F.

17/ Net sediment loss - treated as 0 gain.

* Estimated or assumed.

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SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
			SACRAMENTO, EEL AND RUSSIAN RIVER BASINS (Continued)										
72-19a	Onion Creek No. 5	Onion Creek, trib. of Amer. River.	Soda Springs, Calif.	0.39	0.39	— 1957	—	0.177	0.098	—	—	—	FS
	do	do	do	—	—	— 1958	1.0	.112	.037	—	0.1248	—	
	do	do	do	—	—	— 1959	1.0	.108	.033	—	.0256	—	
	do	do	do	—	—	— 1960	1.0	.046	.015	—	.1790	—	
72-20a	Onion Creek No. 7	do	do	.80	.80	— 1958	—	.0754	.025	—	—	—	FS
	do	do	do	—	—	— 1959	1.0	.0723	.024	—	.0069	—	
	do	do	do	—	—	— 1960	1.0	.0605	.020	—	.0010	—	
72-21	Lee Trentadue	Trib. of Dry Creek	Geyserville, Calif.	.038	.037	Aug. 1961 1/	—	1/10.30	*.221	—	—	—	SCS
	do	do	do	—	—	Oct. 1965	4	9.86	*.211	*66	2.97	4,269	
72-22	Hazel Hill	do	do	.175	.173	Oct. 1960 1/	—	1/21.50	*.099	—	—	—	SCS
	do	do	do	—	—	Oct. 1965	5	21.04	*.097	*65	.52	736	
72-23	Babe Wood	do	Cloverdale, Calif.	1.69	1.68	Oct. 1958 1/	—	1/54.85	*.027	—	—	—	SCS
	do	do	do	—	—	Nov. 1965	7	46.76	*.023	*78.9	.69	1,186	
72-24	Nielson	Trib. of Santa Rosa Creek	Santa Rosa, Calif.	.187	.184	Nov. 1960 2/	—	2/17.36	.092	—	—	—	SCS
	do	do	do	—	—	Nov. 1964	4	16.62	.088	*65	.96	1,359	
72-25	Lee Prediani	Seven Oaks Creek	Healdsburg, Calif.	.594	.592	Oct. 1960 3/	—	3/6.78	*.010	—	—	—	SCS
	do	do	do	—	—	Oct. 1965	5	6.61	*.007	6/87	.73	1,383	
72-26a	Casper Creek - South Fork	Casper Creek	Casper, Calif.	1.63	1.63	Fall 1962	—	—	—	—	—	—	FS
	do	do	do	—	—	Summer 1963	.80	—	—	—	.054	—	
	do	do	do	—	—	Summer 1964	1.0	—	—	—	.028	—	
	do	do	do	—	—	Summer 1965	1.0	—	—	—	.139	—	
	do	do	do	—	—	Summer 1966	1.0	—	—	—	.119	—	
	do	do	do	—	—	Summer 1967	1.0	—	—	—	.068	—	
	do	do	do	—	—	Summer 1968	1.0	—	—	—	.083	—	
	do	do	do	—	—	Summer 1969	1.0	—	—	—	.143	—	
	do	do	do	—	—	Summer 1970	1.0	—	—	—	.091	—	
72-27a	Casper Creek - North Fork	do	Fort Bragg, Calif.	1.92	1.92	Fall 1962	—	—	—	—	—	—	FS
	do	do	do	—	—	Summer 1963	.78	—	—	—	.039	—	
	do	do	do	—	—	Summer 1964	1.0	—	—	—	.043	—	
	do	do	do	—	—	Summer 1965	1.0	—	—	—	.425	—	
	do	do	do	—	—	Summer 1966	1.0	—	—	—	.491	—	
	do	do	do	—	—	Summer 1967	1.0	—	—	—	.037	—	
	do	do	do	—	—	Summer 1968	1.0	—	—	—	.053	—	
	do	do	do	—	—	Summer 1969	1.0	—	—	—	.262	—	
	do	do	do	—	—	Summer 1970	1.0	—	—	—	.141	—	
72-28	McGuire	Virgin Creek	Fort Bragg, Calif.	.084	.083	July 1954 5/	—	7.3	.11	—	—	—	SCS
	do	do	do	—	—	July 1967	13	7.07	.11	*60	.21	274	
72-29	Lazy Creek	Lazy Creek	Philo, Calif.	.666	.663	Aug. 1955 5/	—	26.94	.038	—	—	—	SCS
	do	do	do	—	—	July 1967	12	19.90	.027	67	.94	1,372	
72-30	Appleton	Unnamed	Healdsburg, Calif.	.166	.161	Aug. 1950 5/	—	25.18	.189	—	—	—	SCS
	do	do	do	—	—	Aug. 1967	17	24.24	.182	59	.37	475	
72-31	N. S. Wilson	Bourns Gulch	Gualala, Calif.	.285	.283	July 1952 5/	—	14.06	*.040	—	—	—	SCS
	do	do	do	—	—	July 1967	15	13.02	*.037	*60	.24	314	
			KLAMATH, ROGUE, AND UMPQUA RIVER BASINS										
73-1	Emigrant Gap	Emigrant Creek	Ashland, Oreg.	61.6	61.2	Oct. 1924	—	6/8,300	—	—	—	—	BR
	do	do	do	—	—	Oct. 1951	27	7,500	—	—	.214	—	
73-2	Coyote Creek #1	Trib. South Umpqua River	Tiller, Oreg.	.267	.267	June 1965	—	7/.019	.0001	—	—	—	FS
	do	do	do	—	—	Aug. 1966	1.12	—	—	—	.0052	—	
	do	do	do	—	—	Aug. 1967	1.01	—	—	—	.0005	—	
	do	do	do	—	—	Aug. 1968	1.0	—	—	—	.0016	—	
	do	do	do	—	—	July 1969	.94	—	—	—	.0002	—	
	do	do	do	—	—	July 1970	.98	—	—	—	.0019	—	
73-3	Coyote Creek #2	do	do	.264	.264	June 1965	—	7/.012	.00004	—	—	—	FS
	do	do	do	—	—	Aug. 1966	1.11	—	—	—	.0031	—	
	do	do	do	—	—	Aug. 1967	1.01	—	—	—	.0003	—	
	do	do	do	—	—	Aug. 1968	1.0	—	—	—	.0004	—	
	do	do	do	—	—	July 1969	.94	—	—	—	.0002	—	
	do	do	do	—	—	July 1970	.98	—	—	—	.0004	—	
73-4	Coyote Creek #3	do	do	.192	.192	June 1965	—	7/.011	.0001	—	—	—	FS
	do	do	do	—	—	Aug. 1966	1.11	—	—	—	.0147	—	
	do	do	do	—	—	Aug. 1967	1.01	—	—	—	.002	—	
	do	do	do	—	—	Aug. 1968	1.0	—	—	—	.0023	—	
	do	do	do	—	—	July 1969	.94	—	—	—	.001	—	
	do	do	do	—	—	July 1970	.98	—	—	—	.0057	—	

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73-5	Coyote Creek #4	Trib. South Umpqua River	Tiller, Oreg.	.188	.188	June	1965	--	1/ --	--	--	--	--	FS
	do	do	do	--	--	Aug.	1966	1.11	--	--	--	.0094	--	
	do	do	do	--	--	Aug.	1967	1.01	--	--	--	.0009	--	
	do	do	do	--	--	Aug.	1968	1.0	--	--	--	.0027	--	
	do	do	do	--	--	July	1969	.94	--	--	--	.001	--	
	do	do	do	--	--	July	1970	.98	--	--	--	.0049	--	

LOWER COLUMBIA RIVER BASIN AND PACIFIC COAST BASINS IN NORTHERN OREGON

74-1	Condit (White Salmon)	White Salmon River	Underwood, Wash.	337	337	--	1913	--	8/ 1,081	--	--	--	--	SCS
	do	do	do	--	--	May	1936	23	1,054	--	--	.004	--	
74-2	Lake Harriet (Oak Grove)	Trib. of Clackamas River	Portland, Oreg.	126	126	Aug.	1924	--	256	.001	--	--	--	SCS
	do	do	do	--	--	Aug.	1948	24	252	.001	--	.0013	--	
74-3	McKay	McKay Creek	Pendleton, Oreg.	186	184	Oct.	1926	--	73,737	--	--	--	--	SCS
	do	do	do	--	--	July	1946	19.75	73,474	--	*40	.07	61	
74-4	Cottage Grove	Coast Fk. Willamette River	Cottage Grove, Oreg.	104	102	Oct.	1942	--	33,000	*.165	--	--	--	CE
	do	do	do	--	--	Dec.	1947	5.1	32,873	*.164	--	.244	--	
74-5a	Luther Claypool Pond	Trib. of Beaver Creek	Post, Oreg.	1.09	1.09	--	1946	--	3.79	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	5	3.59	--	*70	.037	56.4	
74-6	Paul Jaegar No. 1 Pond	Trib. of John Day River	Condon, Oreg.	.625	.624	--	1943	--	1.82	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	8	1.40	--	*70	.085	130	
74-7	Paul Jaegar No. 2 Pond	Trib. of Rock Creek	do	.468	.467	--	1946	--	3.19	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	5	2.51	--	*70	.299	456	
74-8a	Paul Jaegar No. 3 Pond	Trib. of John Day River	do	.250	.249	--	1944	--	3.04	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	7	2.81	--	*70	.12	183	
74-9	J. M. Wilson Pond	Trib. of Deschutes River	Moro, Oreg.	1.50	1.50	--	1946	--	1.08	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	5	.97	--	*70	.01	15.24	
74-10	Willard Barnet Pond	Buck Creek	Kent, Oreg.	.210	.209	--	1941	--	2.91	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	10	2.41	--	*70	.24	366	
74-11	Arthur Schmidt Pond	Trib. of Buck Creek	Shaniko, Oreg.	.115	.114	--	1940	--	2.00	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	11	1.97	--	*70	.03	45.73	
74-12	Rock Creek Improvement Co.	Trib. of White River	Tygh Valley, Oreg.	5.62	5.60	--	1938	--	250	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951 9/	13	247	--	*70	.045	68.61	
74-13	Vernon Christ Pond	Five Mile Creek	Dufur, Oreg.	.089	.088	--	1941	--	1.61	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	10	1.39	--	*70	.227	346	
74-14	Milt J. Martin Pond	Mill Creek	The Dalles, Oreg.	.070	.069	--	1944	--	2.72	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	7	2.58	--	*70	.29	442	
74-15	Hunt Livestock Co. Pond	Trib. of Buck Creek	Shaniko, Oreg.	.050	.050	--	1942	--	2.25	--	--	--	--	SCS
	do	do	do	--	--	Oct.	1951	9	2.15	--	*70	.20	305	
74-16	Cold Springs	Cold Springs Canyon	Cold Springs, Oreg.	188	186	Feb.	1908	--	49,709	--	--	--	--	SCS
	do	do	do	--	--	May	1951	43	44,668	--	78	.63	1,070	
74-17	Dorena	Row River	Cottage Grove, Oreg.	265	262	Oct.	1949	--	77,500	.143	--	--	--	CE
	do	do	do	--	--	Sept.	1958	8.9	77,150	.142	--	.150	--	
74-18	H. J. Andrews #1	Trib. Blue River	Blue River, Oreg.	.37	.37	Aug.	1965	--	7/ .12	.0001	--	--	--	FS
	do	do	do	--	--	Aug.	1966	1.05	--	--	--	.011	--	
	do	do	do	--	--	July	1967	.92	--	--	--	.214	--	
	do	do	do	--	--	Aug.	1968	.99	--	--	--	.243	--	
	do	do	do	--	--	Aug.	1969	.84	--	--	--	.332	--	
	do	do	do	--	--	Aug.	1970	.96	--	--	--	.095	--	
74-19	H. J. Andrews #2	do	do	.233	.233	Aug.	1965	--	7/ .056	.0001	--	--	--	FS
	do	do	do	--	--	Aug.	1966	.98	--	--	--	.0311	--	
	do	do	do	--	--	July	1967	.92	--	--	--	0	--	
	do	do	do	--	--	Aug.	1968	.99	--	--	--	.0013	--	
	do	do	do	--	--	Aug.	1969	1.0	--	--	--	.0157	--	
	do	do	do	--	--	Aug.	1970	1.0	--	--	--	.0155	--	
74-20	H. J. Andrews #3	do	do	.391	.391	Dec.	1965	--	7/ .061	.00005	--	--	--	FS
	do	do	do	--	--	Apr.	1966	.31	--	--	--	--	--	
	do	do	do	--	--	Aug.	1967	.97	--	--	--	.054	--	
	do	do	do	--	--	Aug.	1968	1.0	--	--	--	.041	--	
	do	do	do	--	--	Aug.	1969	1.0	--	--	--	.10	--	
	do	do	do	--	--	Aug.	1970	.96	--	--	--	.076	--	

1/ Original capacity determined by 1965 survey.
2/ Original capacity determined from 1964 survey. Capacity shown is for an elevation 4 ft. below spillway crest.
3/ Original capacity obtained during 1965 survey. Total capacity with flashboards = 9.21 ac.-ft.
4/ From one disturbed and two undisturbed samples.
5/ Original capacity determined from 1967 survey.
6/ Based on original topographic survey; believed to be unreliable.
7/ Sediment measured and removed periodically.
8/ Dam was raised 5 feet in 1927.
9/ Built in 1941. Reservoir was thoroughly cleaned in 1945.
* Estimated or assumed.

SUMMARY OF

RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG ANN INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
	COLUMBIA RIVER BASIN (GRAND COULEE TO UMATILLA) AND PACIFIC COAST DRAINAGE IN WASHINGTON Yakima, Chelan, and Okanogan River Basins												
75-1	Diablo	Skagit River	Bellingham, Wash.	1,100	1,100	-- 1930	--	89,220	--	--	--	--	SCS
	do	do	do	—	—	July 1936	6	88,862	--	--	0.054	—	
75-2	High Valley Ranch #1 Pond	Wenas Creek	Yakima, Wash.	4.11	4.10	— 1939	--	8.61	--	—	—	—	SCS
	do	do	do	—	—	Oct. 1951	12	7.63	—	*70	.02	30.49	
75-3	High Valley Ranch #2 Pond	do	Ellensburg, Wash.	.184	.184	— 1940	—	.58	--	--	—	—	SCS
	do	do	do	—	—	Oct. 1951	11	.51	—	*70	.04	61.0	
75-4	High Valley Ranch #3 Pond	do	do	.312	.312	— 1940	—	1.53	—	—	--	--	SCS
	do	do	do	--	--	Oct. 1951	11	1.42	—	*70	.03	46.0	
75-5	Henry Clerf Pond	Rye Grass Creek	do	6.47	6.47	-- 1946	—	2.38	—	--	—	—	SCS
	do	do	do	--	--	Oct. 1951	5	2.02	--	*70	.01	15.24	
75-6	Coffin Sheep Co. Pond	Naches River	Yakima, Wash.	.482	.480	— 1939	—	2.63	—	--	--	—	SCS
	do	do	do	—	—	Oct. 1951	12	2.47	—	*70	.027	41.16	
75-7	Fox Creek	Fox	Ardenvoir, Wash.	1.82	1.82	Summer 1965	—	1/—	—	—	--	--	FS
	do	do	do	—	—	Summer 1966	1	—	—	110	.0076	18.4	
	do	do	do	—	—	Summer 1967	1	—	—	—	.0076	18.4	
	do	do	do	—	—	Summer 1968	1	—	—	—	.0022	5.3	
	do	do	do	—	—	Summer 1969	1	—	—	—	.0076	18.4	
	do	do	do	—	—	Summer 1970	1	—	—	—	0	0	
	do	do	do	—	—	Summer 1971	1	—	—	—	.0577	136.5	
75-8	Burns	Burns	do	2.18	2.18	Summer 1965	—	1/—	—	—	—	—	FS
	do	do	do	—	—	Summer 1966	1	—	—	—	.0	0	
	do	do	do	—	—	Summer 1967	1	—	—	—	.0	0	
	do	do	do	—	—	Summer 1968	1	—	—	—	.0	0	
	do	do	do	—	—	Summer 1969	1	—	—	—	.0	0	
	do	do	do	—	—	Summer 1970	1	—	—	—	.0	0	
	do	do	do	—	—	Summer 1971	1	—	—	110	.0366	87.9	
75-9	McCree	McCree	do	1.985	1.985	Summer 1965	—	1/—	—	—	—	—	FS
	do	do	do	—	—	Summer 1966	1	—	—	—	0	0	
	do	do	do	—	—	Summer 1967	1	—	--	—	0	0	
	do	do	do	—	—	Summer 1968	1	—	—	—	0	0	
	do	do	do	—	—	Summer 1969	1	—	--	—	0	0	
	do	do	do	—	—	Summer 1970	1	—	--	—	0	0	
	do	do	do	—	—	Summer 1971	1	—	--	110	.0165	39.7	
75-10	Crabtree	Trib. White	Auburn, Wash.	.475	.11	May 1967	—	6.92	.01	—	—	—	SCS
	do	do	do	—	--	June 1970	3	6.38	.009	*60	1.65	2,156	
75-11	Llewellyn	Trib. Goose	Wilbur, Wash.	1.25	1.25	July 1957	—	17.52	.26	--	—	—	SCS
	do	do	do	—	--	July 1967	10	8.42	.13	*80	.73	1,272	
75-12	Schwisow	No name	Ritzville, Wash.	4.15	4.15	May 1959	--	3.54	.04	—	—	—	SCS
	do	do	do	—	—	May 1969	10	0	--	*80	.09	156.8	
75-13	Rex Lyle	do	do	.71	.71	June 1959	—	2.75	.2	—	--	--	SCS
	do	do	do	--	—	May 1969	10	1.66	.12	*80	.155	270	
75-14	Schoesler	do	do	.31	.31	June 1951	--	2.24	.37	—	--	—	SCS
	do	do	do	—	—	May 1969	18	0	—	*80	.40	696.8	
75-15	John Landa (FU 90, BLK. 81)	do	Moses Lake, Wash.	.092	.092	Jan. 1970	—	2/—	—	--	—	—	SCS
	do	do	do	—	—	Sept. 1970	1	--	--	*60	.8	1,045	
75-16	Shaffer	do	do	.356	.356	June 1958	—	2/--	—	--	—	—	SCS
	do	do	do	--	--	Nov. 1970	12	--	--	*60	.28	366	
75-17	Sun Spiced No. 1	do	do	.17	.17	-- 1969	--	2/--	--	—	—	—	SCS
	do	do	do	--	—	Sept. 1970	1	--	—	*60	.73	954	
75-18	Sun Spiced No. 2	do	do	.80	.80	June 1969	--	2/--	—	—	--	—	SCS
	do	do	do	--	—	Sept. 1970	1	—	—	*60	.52	680	
75-19	Sheffels	do	Wilbur, Wash.	4.77	4.77	Apr. 1963	--	5.1	.02	—	—	--	SCS
	do	do	do	—	--	May 1969	6	.85	.003	*70	.15	229	
75-20	Telecky	Trib. Crab	Edwall, Wash.	2.26	2.26	Apr. 1957	--	13.43	.09	—	—	—	SCS
	do	do	do	—	—	June 1964	7	0	—	*80	.85	1,480	
75-21	Terwilliger (FU 273, BLK. 1)	No Name	Warden, Wash.	.05	.05	Apr. 1968	—	2/--	—	—	—	—	SCS
	do	do	do	--	—	Dec. 1968	1	--	--	*60	1.4	1,829	
	do	do	do	--	—	Dec. 1969	1	—	--	*60	8.6	11,238	
75-22	Roby	Goose Creek	Davenport, Wash.	4.10	3.85	-- 1938	—	22.91	.10	—	--	--	SCS
	do	do	do	—	—	Apr. 1969	30	2.56	.01	*70	.175	266	

COLUMBIA RIVER BASIN (INTERNATIONAL BOUNDARY TO GRAND COULEE) AND PACIFIC COAST DRAINAGE IN WASHINGTON

Pendorielle, Spokane, Walla Walla, and Lower Snake River Basins

76-1	Mrs. Weiss No. 1 Pond	Asotin Creek	Asotin, Wash.	.129	.128	— 1945	—	1.45	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	6	1.23	—	*70	.31	473	
76-2	Mrs. Weiss No. 2 Pond	Trib. of Asotin Creek	do	.218	.217	— 1945	—	2.54	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	6	2.14	—	*70	.31	473	
76-3a	Lester Reeves No. 1 Pond	Asotin Creek N. & S. Fork	do	.101	.100	— 1941	—	1.45	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	10	1.18	—	*70	.27	4,116	
76-4	Lester Reeves No. 2 Pond	Asotin Creek	do	.125	.125	— 1945 3/	—	1.21	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	6	.69	—	*70	.70	1,067	
76-5	Ben Holt Pond	Latah Creek	Waverly, Wash.	.110	.109	— 1944	—	2.20	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1951	7	2.11	—	*70	.12	183	
76-6	Roy T. Wood Pond	Trib. of Clearwater River	Lewiston, Idaho	.014	.013	— 1946	—	4.22	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	5	3.87	—	*70	5.38	8,202	
76-7	Ed Knowlton Pond	Clearwater River	Orofino, Idaho	.021	.020	— 1946	—	2.54	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	5	2.12	—	*70	4.20	6,403	
76-8	Weldon Wasem Pond	do	Nez Pierce, Idaho	.015	.014	— 1945	—	4.58	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	6	4.40	—	*70	2.14	3,263	
76-9	Henry Kortemeier Pond	Palouse River	Potlatch, Idaho	.021	.020	— 1943	—	2.71	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	8	2.52	—	*70	1.20	1,830	
76-10	George Hoidal Pond	do	Harvard, Idaho	.043	.042	— 1941	—	2.49	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	10	2.41	—	*70	.19	290	
76-11a	Johanna Nelson Pond	do	Deary, Idaho	.014	.012	— 1943	—	5.16	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	8	4.97	—	*70	2.0	3,050	
76-12	Ed Galloway Pond	do	do	.014	.014	— 1944	—	1.29	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	7	1.23	—	*70	.64	976	
76-13	A. E. Tweedy Pond	Clearwater River	Nez Pierce, Idaho	.014	.014	— 1931	—	.80	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	20	.62	—	*70	.64	976	
76-14	Walla Walla River Arm McNary Reservoir	Walla Walla River	Wallula, Wash.	1,760	1,760	Apr. 1953	—	9,668	.023	—	—	—	CE
	do	do	do	—	—	Nov. 1956	3.62	7,237	.017	*75	.405	662	
	do	do	do	—	—	Nov. 1958	2.00	5,507	.013	—	.484	791	
	do	do	do	—	—	Nov. 1960	2.00	4,656	.011	—	.255	417	
	do	do	do	—	—	Sept. 1961	.83	3,569	.008	—	.744	1,215	
	do	do	do	—	—	Sept. 1962	1.00	3,458	.008	—	.073	119	
	do	do	do	—	—	Sept. 1963	1.00	2,918	.007	*75	.307	501	
	do	do	do	—	—	Oct. 1964	1.08	2,874	.007	—	.023	38	
	do	do	do	—	—	July 1965	.75	1,912	.004	—	4/1.027	4/1,678	
76-15	Main Fork Horse Creek	Horse Creek	Elk City, Idaho	6.51	6.51	Oct. 1965	—	1/.087	—	—	—	—	FS
	do	do	do	—	—	Oct. 1966	1	—	—	*90	.0024	4.8	
	do	do	do	—	—	Oct. 1967	1	—	—	*90	.0064	12.9	
	do	do	do	—	—	Oct. 1968	1	—	—	*90	.0024	4.7	
	do	do	do	—	—	Oct. 1969	1	—	—	*90	.0043	8.5	
	do	do	do	—	—	Oct. 1970	1	—	—	*90	.0048	9.4	
	do	do	do	—	—	Oct. 1971	1	—	—	*90	.0134	26.2	
76-16	East Fork Horse Creek	East Fork Horse Creek	do	5.56	5.56	Oct. 1965	—	1/.039	—	—	—	—	FS
	do	do	do	—	—	Oct. 1966	1	—	—	*90	.0022	4.1	
	do	do	do	—	—	Oct. 1967	1	—	—	*90	.0056	11.0	
	do	do	do	—	—	Oct. 1968	1	—	—	*90	.0016	3.8	
	do	do	do	—	—	Oct. 1969	1	—	—	*90	.0029	5.6	
	do	do	do	—	—	Oct. 1970	1	—	—	*90	.0045	8.8	
	do	do	do	—	—	Oct. 1971	1	—	—	*90	.0070	13.7	

COLUMBIA RIVER BASIN IN CANADA

77-

SNAKE RIVER BASIN (FROM KING HILL TO GRANDE RONDE RIVER)

78-1	Orchard	Indian Creek	Boise, Idaho	43	42.8	— 1892	—	4,737	—	—	—	—	SCS
	do	do	do	—	—	June 1947	55	4,668	—	—	.03	—	
78-2	Black Canyon	Payette River	Emmett, Idaho	2,750	5/2,540	June 1924	—	37,659	.017	—	—	—	SCS
	do	do	do	—	—	June 1936	12	33,622	.015	—	.132	—	
78-3	Pleasant Valley	Black's Creek	Boise, Idaho	*16	*16	— 1905	—	7,897	—	—	—	—	SCS
	do	do	do	—	—	June 1947	42	7,855	—	—	.063	—	
78-4	Arrowrock-Boise Project	Boise River	do	2,211	2,170	Feb. 1915	—	279,250	.186	—	—	—	BR
	do	do	do	—	—	Oct. 1947	32.6	271,590	.181	73	.109	173.3	
78-5	Andy Anderson Pond	Weiser River	Cambridge, Idaho	.614	.590	— 1905	—	104.20	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1951	46	100.67	—	*70	.136	207	
78-6	Milton Branch Pond	Trib. of Weiser River	do	.436	.424	— 1940	—	44.49	—	—	—	—	
	do	do	do	—	—	Sept. 1951	11	43.24	—	*70	.259	395	

1/ Sediment measured and removed periodically.
2/ Desilting structure for return irrigation water.
3/ Built 1941. Reservoir was thoroughly cleaned in 1945.
4/ Includes above crest deposits within original flow lines.
5/ Does not include drainage area above Payette Lakes.
* Estimated or assumed.

SUMMARY OF
RESERVOIR SEDIMENTATION SURVEYS MADE IN THE UNITED STATES THROUGH 1970

DATA SHEET NUMBER	RESERVOIR	STREAM	NEAREST TOWN	DRAINAGE AREA (SQUARE MILES)		DATE OF SURVEY	PERIOD BETWEEN SURVEYS (YEARS)	STORAGE CAPACITY (ACRE-FT.)	CAPACITY AVG. ANN. INFLOW RATIO (ACRE-FT. PER ACRE-FT)	SPECIFIC WEIGHT (DRY) (LB. PER CU. FT.)	AVG. ANN. SEDIMENT ACCUMULATION PER SQ. MI. OF NET DR. AREA FOR PERIOD SHOWN		AGENCY SUPPLYING DATA
				TOTAL	NET						AC.-FT.	TONS	
SNAKE RIVER BASIN (FROM KING HILL TO GRANDE RONDE RIVER) (Continued)													
78-7	W. B. Winninger Pond	Trib. of Wester River	Cambridge, Idaho	0.543	0.538	— 1943	—	17.58	—	—	—	—	SCS
	do	do	do	—	—	Aug. 1951	8	16.57	—	*70	0.240	366	
78-8	Miller Smead Pond	Little Willow Creek	Payette, Idaho	.218	.217	— 1945	—	2.90	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	6	2.71	—	*70	.147	224	
78-9	Twin Puddles Pond	Trib. of Boise River	Boise, Idaho	1.61	1.61	— 1941	—	7.82	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	10	7.52	—	*70	.02	30.49	
78-10	Lambkin Pond	do	Mountain Home, Idaho	.193	.191	— 1941	—	4.54	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	10	4.49	—	*70	.05	76.23	
78-11	Mud Springs Pond	do	do	1.07	1.06	— 1939	—	12.18	—	—	—	—	SCS
	do	do	do	—	—	Sept. 1951	12	11.81	—	*70	.03	45.73	
78-12	J. J. Colton Pond	Trib. of Powder River	Keating, Oreg.	.484	.483	— 1939	—	1.08	—	—	—	—	SCS
	do	do	do	—	—	Oct. 1951	12	.84	—	*70	.04	61.0	
78-13	Hawkins Pond No. 1	Trib. of Clover Creek	Westfall, Oreg.	.12	—	— 1952	—	1.56	—	—	—	—	SCS
	do	do	do	—	—	May 1956	4	1.52	—	—	.079	—	
78-14	Hawkins Pond No. 2	do	do	.27	—	— 1952	—	6.94	—	—	—	—	SCS
	do	do	do	—	—	May 1956	4	6.76	—	—	.17	—	
78-15a	Wheaton	Wheaton Creek	do	14.0	—	— 1948	—	52.27	—	—	—	—	SCS
	do	do	do	—	—	May 1956	8	31.97	—	—	.18	—	
78-16	K-1 Creek Sediment Dam	Trib. Silver Creek	Cascade, Idaho	.098	.098	Aug. 1965	—	1/.008	—	—	—	—	FS
	do	do	do	—	—	June 1966	.80	—	—	—	.0002	—	
	do	do	do	—	—	June 1967	.98	—	—	—	.0007	—	
	do	do	do	—	—	July 1968	1.09	—	—	—	.0047	—	
	do	do	do	—	—	Nov. 1968	.35	—	—	—	.0003	—	
	do	do	do	—	—	June 1969	.60	—	—	—	.0409	—	
	do	do	do	—	—	Aug. 1969	.21	—	—	—	0	—	
	do	do	do	—	—	July 1970	.84		—	—	.0194	—	
	do	do	do	—	—	Sept. 1970	.21	—	—	—	0	—	
78-17	Control Creek Sediment Dam	do	do	.775	.775	Aug. 1965	—	1/.023	—	—	—	—	FS
	do	do	do	—	—	June 1966	.79	—	—	—	.0002	—	
	do	do	do	—	—	June 1967	1.0	—	—	—	.0014	—	
	do	do	do	—	—	July 1968	1.07	—	—	—	.0006	—	
	do	do	do	—	—	Nov. 1968	.36	—	—	—	.0011	—	
	do	do	do	—	—	June 1969	.62	—	—	—	.0079	—	
	do	do	do	—	—	Aug. 1969	.17	—	—	—	0	—	
	do	do	do	—	—	June 1970	.83	—	—	—	.0028	—	
	do	do	do	—	—	Sept. 1970	.21	—	—	—	0	—	
78-18	Cabin Creek Sediment Dam	do	do	.40	.40	July 1965	—	1/.046	—	—	—	—	FS
	do	do	do	—	—	June 1966	.87	—	—	—	.0002	—	
	do	do	do	—	—	June 1967	.99	—	—	—	.0008	—	
	do	do	do	—	—	July 1968	1.07	—	—	—	.0028	—	
	do	do	do	—	—	Nov. 1968	.37	—	—	—	.0081	—	
	do	do	do	—	—	June 1969	.60	—	—	—	.0416	—	
	do	do	do	—	—	Aug. 1969	.19	—	—	—	0	—	
	do	do	do	—	—	June 1970	.82	—	—	—	.0162	—	
	do	do	do	—	—	Sept. 1970	.21	—	—	—	0	—	
78-19	Ditch Creek Sediment Dam	do	do	.41	.41	Sept. 1965	—	1/.023	—	—	—	—	FS
	do	do	do	—	—	June 1966	.75	—	—	—	.0006	—	
	do	do	do	—	—	June 1967	1.0	—	—	—	.0107	—	
	do	do	do	—	—	July 1968	1.07	—	—	—	.0039	—	
	do	do	do	—	—	Nov. 1968	.36	—	—	—	.002	—	
	do	do	do	—	—	June 1969	.56	—	—	—	.067	—	
	do	do	do	—	—	Aug. 1969	.23	—	—	—	0	—	
	do	do	do	—	—	June 1970	.82	—	—	—	.0214	—	
	do	do	do	—	—	Sept. 1970	.21	—	—	—	0	—	
78-20	"C" Creek Sediment Dam	do	do	.75	.75	Aug. 1965	—	1/.0207	—	—	—	—	FS
	do	do	do	—	—	June 1966	.80	—	—	—	.0103	—	
	do	do	do	—	—	June 1967	.98	—	—	—	.007	—	
	do	do	do	—	—	July 1968	1.08	—	—	—	.00011	—	
	do	do	do	—	—	Oct. 1968	.30	—	—	—	.0177	—	
	do	do	do	—	—	June 1969	.60	—	—	—	.04	—	
	do	do	do	—	—	Aug. 1969	.24	—	—	—	0	—	
	do	do	do	—	—	June 1970	.82	—	—	—	.0276	—	
	do	do	do	—	—	Sept. 1970	.21	—	—	—	0	—	
78-21	"D" Creek Sediment Dam	do	do	.47	.47	July 1965	—	1/.017	—	—	—	—	FS
	do	do	do	—	—	June 1966	.85	—	—	—	.0017	—	
	do	do	do	—	—	June 1967	.99	—	—	—	.0187	—	

	——do——	——do——	——do——	—	—	July 1968	1.09	—	—	—	.002	—	
	——do——	——do——	——do——	—	—	Nov. 1968	.35	—	—	—	.0036	—	
	——do——	——do——	——do——	—	—	June 1969	.57	—	—	—	.0194	—	
	——do——	——do——	——do——	—	—	Aug. 1969	.22	—	—	—	0	—	
	——do——	——do——	——do——	—	—	June 1970	.82	—	—	—	.0015	—	
	——do——	——do——	——do——	—	—	Sept. 1970	.21	—	—	—	0	—	
78-22	Eggers Creek Sediment Dam——	——do——	——do——	.5	.5	Aug. 1965	—	[1].013	—	—	—	—	FS
	——do——	——do——	——do——	—	—	June 1966	.81	—	—	—	.0012	—	
	——do——	——do——	——do——	—	—	June 1967	1.01	—	—	—	.0054	—	
	——do——	——do——	——do——	—	—	July 1968	1.08	—	—	—	.0013	—	
	——do——	——do——	——do——	—	—	Nov. 1968	.35	—	—	—	.0012	—	
	——do——	——do——	——do——	—	—	June 1969	.58	—	—	—	[2]0	—	
	——do——	——do——	——do——	—	—	Aug. 1969	.21	—	—	—	0	—	
	——do——	——do——	——do——	—	—	June 1970	.82	—	—	—	.013	—	
	——do——	——do——	——do——	—	—	Sept. 1970	.21	—	—	—	0	—	

SNAKE RIVER BASIN (ABOVE KINGS HILL) AND SALMON RIVER BASIN

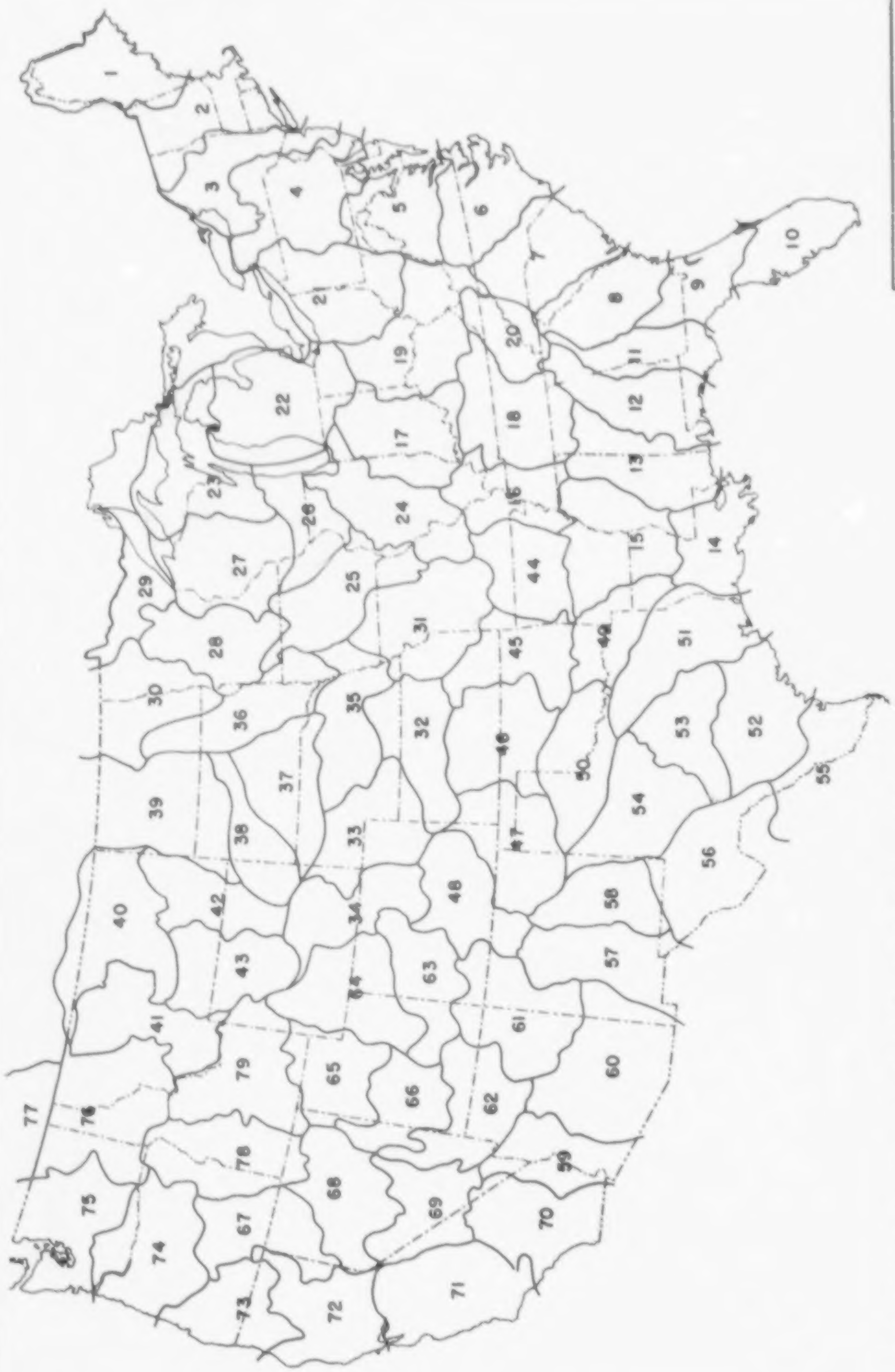
79-1	Rattlesnake Butte Pond——	Big Wood River——	Gooding, Idaho——	4.81	4.80	— 1943	—	25.56	—	—	—	—	SCS
	——do——	——do——	——do——	—	—	Sept. 1951	8	23.89	—	*70	.04	61	
79-2	Salmon Falls——	Salmon Falls Creek——	Rogerson, Idaho——	1,560	1,555	— 1910	—	229,650	—	—	—	—	SCS
	——do——	——do——	——do——	—	—	Oct. 1955	45.0	227,282	—	*50	.034	37	
79-3	Pioneer——	Clover Creek——	Glenns Ferry, Idaho——	183	183	— 1904	—	1,264	—	—	—	—	SCS
	——do——	——do——	——do——	—	—	Aug. 1954	50±	898	—	—	.04	—	
79-4	Tailholt "A" Creek Sediment Dam	Trib. South Fork Salmon——	Yellow Pine, Idaho——	.845	.84	Aug. 1967	—	[1].0164	—	—	—	—	FS
	——do——	——do——	——do——	—	—	May 1968	.74	—	—	—	.001	—	
	——do——	——do——	——do——	—	—	Oct. 1968	.34	—	—	—	.0002	—	
	——do——	——do——	——do——	—	—	May 1969	.63	—	—	—	.0199	—	
	——do——	——do——	——do——	—	—	Sept. 1969	.34	—	—	—	.0017	—	
	——do——	——do——	——do——	—	—	June 1970	.72	—	—	—	.017	—	
	——do——	——do——	——do——	—	—	Sept. 1970	.23	—	—	—	0	—	
79-5	Tailholt "B" Creek Sediment Dam	——do——	——do——	.61	.61	Aug. 1967	—	[1].012	—	—	-	—	FS
	——do——	——do——	——do——	—	—	May 1968	.74	—	—	—	.0015	—	
	——do——	——do——	——do——	—	—	Oct. 1968	.40	—	—	—	.0086	—	
	——do——	——do——	——do——	—	—	May 1969	.64	—	—	—	.0156	—	
	——do——	——do——	——do——	—	—	Sept. 1969	.34	—	—	—	.0067	—	
	——do——	——do——	——do——	—	—	June 1970	.72	—	—	—	.0159	—	
79-6	Tailholt "C" Sediment Dam——	Trib. South Fork Salmon——	Yellow Pine, Idaho——	.556	.548	Aug. 1967	—	[1].015	—	—	—	—	FS
	——do——	——do——	——do——	—	—	May 1968	.74	—	—	—	.0039	—	
	——do——	——do——	——do——	—	—	Oct. 1968	.54	—	—	—	.001	—	
	——do——	——do——	——do——	—	—	May 1969	.62	—	—	—	.0273	—	
	——do——	——do——	——do——	—	—	Sept. 1969	.27	—	—	—	.0009	—	
	——do——	——do——	——do——	—	—	June 1970	.72	—	—	—	.0134	—	
79-7	Tailholt Main Sediment Dam——	——do——	——do——	2.54	[3]2.50	— —	—	[1].0552	—	—	—	—	FS
	——do——	——do——	——do——	—	—	June 1966	.64	—	—	—	.0066	—	
	——do——	——do——	——do——	—	—	Sept. 1966	.29	—	—	—	.0019	—	
	——do——	——do——	——do——	—	—	May 1967	.68	—	—	—	.012	—	
	——do——	——do——	——do——	—	—	Sept. 1967	.33	—	—	—	.0148	—	
	——do——	——do——	——do——	—	—	May 1968	.66	—	—	—	.0081	—	
	——do——	——do——	——do——	—	—	Oct. 1968	.40	—	—	—	.0002	—	
	——do——	——do——	——do——	—	—	May 1969	.64	—	—	—	.0191	—	
	——do——	——do——	——do——	—	—	Oct. 1969	.35	—	—	—	.0037	—	
	——do——	——do——	——do——	—	—	June 1970	.60	—	—	—	.0087	—	
79-8	Circle End Creek Sediment Dam	——do——	——do——	1.452	1.452	— —	—	[1].013	—	—	—	—	FS
	——do——	——do——	——do——	—	—	Apr. 1966	.58	—	—	—	.0169	—	
	——do——	——do——	——do——	—	—	Sept. 1966	.42	—	—	—	.0016	—	
	——do——	——do——	——do——	—	—	May 1967	.65	—	—	—	.0159	—	
	——do——	——do——	——do——	—	—	Sept. 1967	.35	—	—	—	.0163	—	
	——do——	——do——	——do——	—	—	May 1968	.65	—	—	—	.0052	—	
	——do——	——do——	——do——	—	—	Oct. 1968	.40	—	—	—	.0086	—	
	——do——	——do——	——do——	—	—	Apr. 1969	.54	—	—	—	.0144	—	
	——do——	——do——	——do——	—	—	Sept. 1969	.44	—	—	—	.0014	—	
	——do——	——do——	——do——	—	—	June 1970	.70	—	—	—	.0024	—	
79-9	Indian Fork——	Indian Fork——	Ririe, Idaho——	1.6	1.6	— 1929*	—	3.5	*.007	—	—	—	SCS
	——do——	——do——	——do——	—	—	Sept. 1966	41	1.88	*.004	95.3	.025	52	
79-10	Rock Creek——	Rock Creek——	Ammon, Idaho——	6.76	6.76	— 1946*	—	12.6	*.008	—	—	—	SCS
	——do——	——do——	——do——	—	—	Aug. 1966	20	8.96	*.006	79.8	.027	45	

PUERTO RICO

80-1	Caonillas——	Caonillas River——	Utuado, Puerto Rico——	[4]68.9	47.9	June 1948	—	[5]50,149	.566	—	—	—	SCS
	——do——	——do——	——do——	—	—	Nov. 1952	4.3	49,883	.563	38.1	1.29	1,070	

[1] Pond used to take bedload samples and organic matter.
[2] All values lost due to incorrect survey.
[3] Total drainage for this dam includes drainage for Tailholt A, B and C Creeks after 8-22-67.
[4] Caonillas extension project increased the drainage area to 85.5 sq. mi.; put into operation Oct. 1952.
[5] Determined by 1952 survey.
* Estimated or assumed.

INDEX OF RIVER BASIN MAPS



Index number corresponds to first of two numbers in summary table, which appear in column headed "Data Sheet No."

RESERVOIR SEDIMENT DATA SUMMARY

CONCHAS RESERVOIR
NAME OF RESERVOIR

47-1b
DATA SHEET NO.

DAM	1. OWNER Corps of Engineers	2. STREAM Canadian and Conchas	3. STATE New Mexico
	4. SEC. 33 TWP. 14N RANGE 26E	5. NEAREST P.O. Conchas Dam	6. COUNTY San Miguel
	7. LAT 35° 24′ 10″ LONG 104° 11′ 35″	8. TOP OF DAM ELEVATION 4240	9. SPILLWAY CREST ELEV. 4201 1/

RESERVOIR 10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
a. FLOOD CONTROL	4,218	13,715	201,834	601,112	1 Jan. 1939
b. MULTIPLE USE					
c. POWER					16. DATE NORMAL OPER. BEGAN
d. WATER SUPPLY					
e. IRRIGATION					
f. CONSERVATION	4,201	10,073	296,412	399,278	Jan. 1939
g. INACTIVE	4,155	3,520	102,866	102,866	

17. LENGTH OF RESERVOIR Canadian 23 2/ MILES	AV. WIDTH OF RESERVOIR 4200 Contour 0.75 MILES
WATERSHED 18. TOTAL DRAINAGE AREA 7,409 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 15.2 3/ INCHES
19. NET SEDIMENT CONTRIBUTING AREA 6,976 SQ. MI.	23. MEAN ANNUAL RUNOFF 0.4864 4/ (65.6) INCHES
20. LENGTH 100 MILES AV. WIDTH 73 MILES	24. MEAN ANNUAL RUNOFF 192,200 (65.6) AC.-FT.
21. MAX. ELEV. 13,000 MIN. ELEV. 4,074	25. ANNUAL TEMP MEAN 49° RANGE 30-75 3/

SURVEY DATA

26. DATE OF SURVEY 5/	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I. RATIO, AC.-FT. PER AC.-FT.
Jan. 1939			Contour	10 feet	13,715	601,112	3.13
May 1940	1.4	1.4	Range	14 ranges		599,712	3.12
June 1942	2.1	3.4	Range	24 ranges		585,112	3.04
Nov. 1942	.4	3.8	Range	28 ranges		581,112	3.02
Oct. 1944	1.9	5.7	Contour	10 feet	13,340	576,756	3.00
Feb. 1949	4.3	10.1	Contour	10 feet	13,552	566,163	2.95
Oct. 1963	14.7	24.83	Range (D)	45 ranges	13,677	550,799	2.87
Oct. 1970	6.92	31.75	Contour	5 feet	13,664	528,951	2.75

26. DATE OF SURVEY 5/	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE
	Inches					
May 1940	14.26	72,700		101,780	72,700	101,780
June 1942	22.40	859,780	1,059,699	1,805,540	560,980	1,907,320
Nov. 1942	12.50	1,079,980		431,990	615,607	2,339,310
Oct. 1944	14.32	143,750	1,168,350	273,130	458,320	2,612,440
Feb. 1949	13.68	120,500	158,858	518,140	309,960	3,130,580
Oct. 1963	13.01	144,340	336,514	2,121,850	211,790	5,252,430
Oct. 1970	12.04	157,100	394,190	1,087,100	199,670	6,339,530

26. DATE OF SURVEY 5/	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
May 1940	1,400			1,400	1,000	0.143
June 1942	14,600	6,952	0.996	16,000	4,710	.675
Nov. 1942	4,000			20,000	5,260	.754
Oct. 1944	4,356	2,290	.328	24,356	4,270	.612
Feb. 1949	10,593	2,460	.353	34,949	3,460	.496
Oct. 1963	15,364	1,045	.150	50,313	2,030	.291
Oct. 1970	21,848	3,157	.453	72,161	2,278	.326

26. DATE OF SURVEY 5/	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
May 1940	75.7*		336	0.17	0.23	16,687	16,637
June 1942	75.7	1,643	1,113	.78	2.66	9,810	10,177
Nov. 1942	75.7		1,243	.88	3.33	11,233	10,372
Oct. 1944	75.7	541	1,009	.71	4.05	19,348	11,310
Feb. 1949	75.7	581	818	.58	5.81	24,802	12,543
Oct. 1963	75.7	247	479	.54	8.37	8,748	11,621
Oct. 1970	75.7	746	587	.38	12.00	24,376	13,806

*Estimated

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION											
	178-128	128-108	108-88	88-68	68-58	58-48	48-38	38-28	28-Crest	Crest-17	17-29	
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
May 1940												
June 1942												
Nov. 1942												
Oct. 1944	16	4	7	10	6	10	15	16	16			
Feb. 1949	13	4	5	9	5	7	11	14	14	16	2	
Oct. 1963	9	9	8	15	9	11	13	11	8	7		
Oct. 1970	3	7	13	10	5	6	8	11	33	4	1	

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														
May 1940[6]	114	23	3	-26	-16	2				S. Canadian Arm					
	30	22	7	10	18	13				Conchas Arm					
June 1942	6	3	4	4	22	14	27	18	2	S. Canadian Arm					
	20	21	-12	12	13	27	5	14		Conchas Arm					
Nov. 1942	6	2	5	8	16	16	29	16	2	S. Canadian Arm					
	-1	0	1	2	19	57	5	14	3	Conchas Arm					

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.
1947	4,202.46	4,199.00	120,330	1959	4,200.38	4,193.40	112,620
1948	4,201.46	4,195.63	154,700	1960	4,199.37	4,192.68	131,520
1949	4,200.97	4,192.50	153,260	1961	4,201.75	4,196.55	216,440
1950	4,198.59	4,185.85	121,410	1962	4,201.13	4,193.02	119,280
1951	4,194.68	4,184.24	106,770	1963	4,193.01	4,176.16	76,510
1952	4,184.15	4,168.23	126,930	1964	4,178.58	4,156.05	31,060
1953	4,176.16	4,162.07	107,950	1965	4,201.83	4,157.61	394,190
1954	4,173.22	4,155.80	32,030	1966	4,200.77	4,192.25	108,660
1955	4,190.37	4,157.10	297,760	1967	4,195.36	4,185.79	142,740
1956	4,189.98	4,173.19	51,880	1968	4,193.13	4,183.51	113,130
1957	4,175.40	4,163.80	129,930	1969	4,193.65	4,180.65	192,830
1958	4,201.82	4,173.97	336,510	1970	4,197.55	4,189.30	105,630

46. ELEVATION-AREA-CAPACITY DATA

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4,230	16,380	709,110	4,180	5,513	173,912	4,110	311	1,299
4,220	14,110	556,724	4,170	4,323	125,102	4,100	2	24
4,218	13,664	528,951	4,160	3,394	86,519	4,090	1	9
4,210	11,845	426,866	4,150	2,642	56,348	4,080		2
4,201	9,692	330,124	4,140	1,959	33,495	4,070	0	0
4,200	9,463	320,546	4,130	1,323	17,170	4,060	0	0
4,190	7,290	237,119	4,120	797	6,690			

47. REMARKS AND REFERENCES

1/ Emergency Spillway Crest at 4218.
2/ Conchas 13.8 miles.
3/ From climatic Atlas dated June 1968.
4/ This figure affected by water taken out above reservoir for irrigation.
5/ Totals computed to end of each month shown.
6/ Only dates computed.

48. AGENCY MAKING SURVEY Albuquerque District Corps of Engineers

49. AGENCY SUPPLYING DATA Corps of Engineers

50. DATE May 1970

April 1966

RESERVOIR SEDIMENT DATA SUMMARY

NAME OF RESERVOIR

DATA SHEET NO.

DAM	1. OWNER	2. STREAM	3. STATE
	4. SEC. TWP. RANGE	5. NEAREST P.O.	6. COUNTY
	7. LAT. ° ' " LONG. ° ' "	8. TOP OF DAM ELEVATION	9. SPILLWAY CREST ELEV.

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
	a. FLOOD CONTROL					
	b. MULTIPLE USE					
	c. POWER					16. DATE NORMAL OPER. BEGAN
	d. WATER SUPPLY					
	e. IRRIGATION					
	f. CONSERVATION					
	g. INACTIVE					
	17. LENGTH OF RESERVOIR MILES		AV. WIDTH OF RESERVOIR MILES			

WATERSHED	18. TOTAL DRAINAGE AREA SQ. MI.		22. MEAN ANNUAL PRECIPITATION INCHES
	19. NET SEDIMENT CONTRIBUTING AREA SQ. MI.		23. MEAN ANNUAL RUNOFF INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF AC.-F.T.
	21. MAX. ELEV.	MIN. ELEV.	25. ANNUAL TEMP: MEAN RANGE

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I. RATIO, AC.-FT. PER AC.-FT.

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

45. RANGE IN RESERVOIR OPERATION

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.

46. ELEVATION-AREA-CAPACITY DATA

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY

47. REMARKS AND REFERENCES

48. AGENCY MAKING SURVEY

49. AGENCY SUPPLYING DATA

50. DATE ____________________

USDA-SCS HYATTSVILLE MD 1966

April 1966

REFERENCES FOR APPENDIX F

Miscellaneous Publication No. 1266, U.S. Department of Agriculture, Sedimentation Laboratory, Oxford, Mississippi, July, 1973.

APPENDIX G

INITIAL DILUTION TABLES

The Tables are ordered as follows:

Tables N_1	Port Spacing (PS) (Diameters)
1-20	2
21-40	5
41-60	10
61-80	25
81-100	1000 (effluent from each port acts as a single plume)

Tables N_2	Current Velocity to Effluent Velocity Ratio (k)
1-5	0.1
6-10	0.05
11-15	0.02
16-20	0.00 (no current)

Tables N_3	Composite Stratification Parameter (SP)
1	200 (high stratification)
2	500
3	2000
4	10000
5	infinity (no stratification)

After finding N_1, N_2, and N_3 the appropriate Table number is:

$$N_1 + N_2 + N_3 - 2$$

TABLE 1

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.10

```
                                 DENSIMETRIC FROUDE NUMBER

                        1            3             10            30            100           1000
RISE(DIA)   ------------------------------------------------------------------------------------------
            : T)                                                                                      !
            : M)                2.2(  0.4)    2.1(  0.0)    2.1(  0.0)    2.1(  0.0)    2.1(  0.0)    !
    1       :          1.9          2.7           4.3           7.0          13.0          48.5       !
            : T)                                                                                      !
            : M)                                                                                      !
    2       :          2.7          3.3           5.1           8.5          15.8          60.9       !
            : T)                                                                                      !
            : M)                                                                                      !
    3       :          3.5          3.8           5.7           9.5          17.9          70.5       !
            : T)                                                                      75.5(  3.6)    !
            : M)    4.3(  3.7)                                                                        !
    4       :          4.5          4.2           6.2          10.3          19.6          78.7       !
            : T)                                                                                      !
            : M)                                                                                      !
    5       :          5.4          4.7           6.7          11.1          21.1          88.6       !
            : T)                                                                                      !
            : M)                                                                                      !
    7       :          7.0          5.6           7.7          12.6          23.6                     !
            : T)                                                                                      !
            : M)                                                                                      !
    9       :          8.5          6.6           8.6          13.8          26.0                     !
            : T)                                                        27.1( 10.0)                   !
            : M)                                                                                      !
   12       :         10.7          7.8           9.9          15.8          29.4                     !
            : T)                                                                                      !
            : M)                                                                                      !
   15       :         12.8          9.2          11.2          17.6          33.6                     !
            : T)                                           18.1( 15.9)                                !
            : M)                                                                                      !
   20       :         16.1         11.3          13.6          21.0                                   !
            : T)   16.9( 21.3)  13.5( 25.0)   14.3( 21.7)                                             !
            : M)                                                                                      !
   25       :         19.2                       16.2                                                 !
            : T)                                                                                      !
            : M)                                                                                      !
   33       :                      17.5                                                               !
            : T)                                                                                      !
            : M)                                                                                      !
            ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  35.3( 31.0)  26.8( 36.6)  23.0( 32.5)  25.6( 24.8)  37.2( 16.2) 104.0(  5.8)
```

TABLE 2

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.10

```
                                      DENSIMETRIC FROUDE NUMBER

                         1            3             10            30           100          1000
RISE(DIA)   ------------------------------------------------------------------------------------------
            : T)                                                                                     :
            : M)                 2.2(  0.4)   2.1(  0.0)   2.1(  0.0)   2.1(  0.0)   2.1(  0.0)      :
    1       :           1.9          2.7          4.3          7.0         12.9         48.1         :
            : T)                                                                                     :
            : M)                                                                                     :
    2       :           2.7          3.3          5.1          8.4         15.8         60.1         :
            : T)                                                                                     :
            : M)                                                                                     :
    3       :           3.6          3.8          5.7          9.5         17.7         68.5         :
            : T)                                                                                     :
            : M)     4.3(  3.8)                                                                      :
    4       :           4.5          4.2          6.2         10.3         19.4         75.5         :
            : T)                                                                                     :
            : M)                                                                                     :
    5       :           5.4          4.7          6.7         11.1         20.8         81.5         :
            : T)                                                                                     :
            : M)                                                                                     :
    7       :           7.0          5.6          7.6         12.5         23.3         93.0         :
            : T)                                                                     94.3(  7.3)     :
            : M)                                                                                     :
    9       :           8.5          6.6          8.5         13.7         25.3        104.0         :
            : T)                                                                                     :
            : M)                                                                                     :
   12       :          10.9          7.8          9.8         15.5         28.0                      :
            : T)                                                                                     :
            : M)                                                                                     :
   15       :          13.1          9.2         11.0         17.3         30.7                      :
            : T)                                                       35.0( 20.2)                   :
            : M)                                                                                     :
   20       :          16.7         11.4         13.0         20.0                                   :
            : T)                                                                                     :
            : M)                                                                                     :
   25       :          20.3         13.6         15.0         22.8         39.4                      :
            : T)                                          25.6( 30.0)                                :
            : M)                                                                                     :
   33       :          25.5         16.9         18.5         27.5                                   :
            : T)     26.5( 34.8)               21.4( 39.2)                                           :
            : M)                                                                                     :
   42       :          30.7         20.8         22.9         33.4                                   :
            : T)                 21.0( 42.6)                                                         :
            : M)                                                                                     :
   54       :                       26.5         32.2                                                :
            : T)                                                                                     :
            : M)                                                                                     :
            ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  59.3( 50.2)  44.9( 61.0)  36.8( 56.8)  37.0( 45.6)  48.3( 31.9) 131.0( 11.7)
```

TABLE 3

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                   DENSIMETRIC FROUDE NUMBER

                        1            3            10           30           100          1000
RISE(DIA)  ---------------------------------------------------------------------------------------
           : T)                                                                                  :
           : M]                 2.2[  0.4]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   :
    1      :         1.9          2.7          4.3          7.0         12.9         48.1        :
           : T)                                                                                  :
           : M]                                                                                  :
    2      :         2.7          3.3          5.1          8.4         15.8         59.7        :
           : T)                                                                                  :
           : M]                                                                                  :
    3      :         3.6          3.8          5.7          9.5         17.7         67.6        :
           : T)                                                                                  :
           : M]    4.3[  3.8]                                                                    :
    4      :         4.5          4.2          6.2         10.3         19.3         74.0        :
           : T)                                                                                  :
           : M]                                                                                  :
    5      :         5.4          4.7          6.7         11.0         20.7         79.8        :
           : T)                                                                                  :
           : M]                                                                                  :
    7      :         7.0          5.6          7.6         12.4         23.1         89.2        :
           : T)                                                                                  :
           : M]                                                                                  :
    9      :         8.6          6.6          8.5         13.6         25.1         96.9        :
           : T)                                                                                  :
           : M]                                                                                  :
   12      :        10.9          7.9          9.7         15.3         27.7        107.0        :
           : T)                                                                                  :
           : M]                                                                                  :
   15      :        13.2          9.2         10.9         17.0         30.0        116.0        :
           : T)                                                                                  :
           : M]                                                                                  :
   20      :        17.0         11.4         12.8         19.7         33.9        131.0        :
           : T)                                                                    132.0( 20.7)  :
           : M]                                                                                  :
   25      :        20.8         13.6         14.7         22.3         37.5        145.0        :
           : T)                                                                                  :
           : M]                                                                                  :
   33      :        26.7         17.0         17.8         26.3         42.8        176.0        :
           : T)                                                                                  :
           : M]                                                                                  :
   42      :        33.1         21.0         21.3         31.1         48.8                     :
           : T)                                                      56.1( 53.4)                 :
           : M]                                                                                  :
   54      :        41.6         26.2         25.8         37.3         56.7                     :
           : T)                                                                                  :
           : M]                                                                                  :
   70      :        52.0         32.9         32.7         45.9         67.2                     :
           : T)   52.6( 71.3)  41.3( 90.3)  41.1( 89.4)  47.1( 72.5)                             :
           : M]                                                                                  :
   90      :        63.2                      41.6         57.8                                  :
           : T)                                                                                  :
           : M]                                                                                  :
  115      :                     53.1         59.6                                               :
           : T)                                                                                  :
           : M]                                                                                  :
           ---------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 125.0(102.0)  96.1(128.0)  76.2(125.0)  69.5(106.0)  78.7( 82.7) 184.0( 33.4)
```

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                          DENSIMETRIC FROUDE NUMBER

                         1            3            10           30           100          1000
 RISE(DIA)   ------------------------------------------------------------------------------------------
             : T)                                                                                      :
             : M]                  2.2[  0.4]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]  :
     1       :           1.9          2.7          4.3          7.0         12.9         48.1        :
             : T)                                                                                      :
             : M]                                                                                      :
     2       :           2.7          3.3          5.1          8.4         15.8         59.7        :
             : T)                                                                                      :
             : M]                                                                                      :
     3       :           3.6          3.8          5.7          9.5         17.7         67.6        :
             : T)                                                                                      :
             : M]     4.3[  3.8]                                                                      :
     4       :           4.5          4.2          6.2         10.3         19.3         74.0        :
             : T)                                                                                      :
             : M]                                                                                      :
     5       :           5.4          4.7          6.7         11.0         20.7         79.3        :
             : T)                                                                                      :
             : M]                                                                                      :
     7       :           7.0          5.6          7.6         12.4         22.9         88.0        :
             : T)                                                                                      :
             : M]                                                                                      :
     9       :           8.6          6.6          8.5         13.6         24.9         95.6        :
             : T)                                                                                      :
             : M]                                                                                      :
    12       :          10.9          7.9          9.7         15.3         27.7        105.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    15       :          13.3          9.2         10.9         17.0         30.0        113.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    20       :          17.0         11.4         12.8         19.7         33.6        125.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    25       :          21.0         13.6         14.7         22.2         37.2        135.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    33       :          27.1         17.1         17.6         26.2         42.5        149.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    42       :          33.8         21.1         21.0         30.5         48.1        163.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    54       :          42.8         26.3         25.3         36.5         55.3        180.0        :
             : T)                                                                   200.0( 68.9)   :
             : M]                                                                                      :
    70       :          54.9         33.3         31.1         44.0         64.7        201.0        :
             : T)                                                                                      :
             : M]                                                                                      :
    90       :          69.3         41.9         38.3         53.8         76.0        226.0        :
             : T)                                                                                      :
             : M]                                                                                      :
   115       :          87.0         52.6         47.5         66.2         90.4                     :
             : T)                                                                                      :
             : M]                                                                                      :
   148       :         109.0         66.5         60.1         82.9        109.0                     :
             : T) 117.0(161.0)                         101.0(182.0) 110.0(150.0)                     :
             : M]                                                                                      :
   190       :         133.0         83.9         77.5        106.0        133.0                     :
             : T)                  91.5(209.0)  90.4(217.0)                                           :
             : M]                                                                                      :
   244       :                      107.0        107.0        140.0                                  :
             : T)                                                                                      :
             : M]                                                                                      :
             ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 225.0(232.0) 224.0(293.0) 176.0(297.0) 152.0(260.0) 155.0(224.0) 244.0( 99.9)
```

TABLE 5

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.10

```
                                       DENSIMETRIC FROUDE NUMBER

                     1             3             10            30            100           1000
RISE(DIA)  ----------------------------------------------------------------------------------------------
           : M]              2.2[  0.4]    2.1[  0.0]    2.1[  0.0]    2.1[  0.0]    2.1[  0.0]   :
    1      :        1.9        2.7           4.3           7.0          12.9          46.1         :
           : M]                                                                                    :
    2      :        2.7        3.3           5.1           8.4          15.8          59.3         :
           : M]                                                                                    :
    3      :        3.6        3.8           5.7           9.5          17.7          67.6         :
           : M]   4.3[  3.8]                                                                       :
    4      :        4.5        4.2           6.2          10.3          19.3          74.0         :
           : M]                                                                                    :
    5      :        5.4        4.7           6.7          11.0          20.7          79.3         :
           : M]                                                                                    :
    7      :        7.0        5.6           7.6          12.4          22.9          88.0         :
           : M]                                                                                    :
    9      :        8.6        6.6           8.5          13.6          24.9          95.6         :
           : M]                                                                                    :
   12      :       10.9        7.9           9.7          15.3          27.7         105.0         :
           : M]                                                                                    :
   15      :       13.3        9.2          10.9          17.0          30.0         113.0         :
           : M]                                                                                    :
   20      :       17.1       11.4          12.8          19.6          33.6         124.0         :
           : M]                                                                                    :
   25      :       21.0       13.6          14.6          22.2          37.0         133.0         :
           : M]                                                                                    :
   33      :       27.1       17.1          17.6          26.2          42.2         147.0         :
           : M]                                                                                    :
   42      :       34.0       21.1          20.8          30.5          47.8         159.0         :
           : M]                                                                                    :
   54      :       43.1       26.3          25.1          36.2          54.9         174.0         :
           : M]                                                                                    :
   70      :       55.3       33.3          30.9          43.7          64.4         191.0         :
           : M]                                                                                    :
   90      :       71.0       42.2          38.0          53.0          75.5         210.0         :
           : M]                                                                                    :
  115      :       89.6       53.0          46.8          64.5          89.2         232.0         :
           : M]                                                                                    :
  148      :      115.0       67.5          58.3          79.5         107.0                       :
           : M]                                                                                    :
  190      :      147.0       85.8          73.0          98.8         130.0                       :
           : M]                                                                                    :
  244      :      188.0      109.0          92.0         123.0         158.0                       :
           : M]                                                                                    :
           ----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 231.0(300.0) 134.0(301.0) 111.0(300.0) 149.0(300.0) 188.0(301.0) 257.0(147.0)
```

TABLE 6

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.05

```
                                          DENSIMETRIC FROUDE NUMBER

                          1             3             10            30            100           1000
RISE(DIA)  ------------------------------------------------------------------------------------------
           : T)                                                                                    :
           : M)                     2.1(  0.4)    2.1(  0.0)    2.1(  0.0)    2.1(  0.0)    2.1(  0.0) :
    1      :             1.9          2.6           4.0           6.3          10.9          36.5      :
           : T)                                                                                    :
           : M)                                                                                    :
    2      :             2.7          3.2           4.6           7.4          13.0          44.9      :
           : T)                                                                                    :
           : M)                                                                                    :
    3      :             3.6          3.6           5.1           8.1          14.5          51.2      :
           : T)                                                                                    :
           : M)      4.2(  3.7)                                                                    :
    4      :             4.5          4.0           5.5           8.8          15.7          56.5      :
           : T)                                                                      59.3(  4.6)   :
           : M)                                                                                    :
    5      :             5.4          4.4           5.8           9.3          16.7          61.8      :
           : T)                                                                                    :
           : M)                                                                                    :
    7      :             6.9          5.1           6.4          10.2          18.5          74.0      :
           : T)                                                                                    :
           : M)                                                                                    :
    9      :             8.4          5.9           7.0          11.0          20.0                    :
           : T)                                                         22.2( 12.1)                :
           : M)                                                                                    :
   12      :            10.4          7.0           7.7          12.0                                  :
           : T)                                                                                    :
           : M)                                                                                    :
   15      :            12.5          8.1           8.5          13.0          24.2                    :
           : T)                                           14.2( 18.8)                              :
           : M)                                                                                    :
   20      :            15.6          9.8           9.7          14.6                                  :
           : T)     16.5( 21.6)                                                                    :
           : M)                                                                                    :
   25      :            18.4         11.4          10.9          16.5                                  :
           : T)                   12.1( 27.2)   11.1( 25.9)                                        :
           : M)                                                                                    :
   33      :                         13.8          13.0                                            :
           : T)                                                                                    :
           : M)                                                                                    :
           ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  29.4( 31.7)  20.4( 40.7)  17.0( 40.3)  19.6( 30.5)  29.9( 19.6)  81.1(  7.4)
```

TABLE 7

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.05

```
                          DENSIMETRIC FROUDE NUMBER
                1           3          10          30         100        1000
RISE(DIA)  ------------------------------------------------------------------------
           : T)                                                                    :
           : M)         2.1(  0.4)  2.1(  0.0)  2.1(  0.0)  2.1(  0.0)  2.1(  0.0) :
    1      :     1.9       2.6         4.0         6.3        10.9        36.5     :
           : T)                                                                    :
           : M)                                                                    :
    2      :     2.7       3.2         4.6         7.4        13.0        44.6     :
           : T)                                                                    :
           : M)                                                                    :
    3      :     3.6       3.6         5.1         8.1        14.4        50.2     :
           : T)                                                                    :
           : M)  4.3(  3.7)                                                        :
    4      :     4.5       4.0         5.5         8.8        15.6        54.9     :
           : T)                                                                    :
           : M)                                                                    :
    5      :     5.4       4.4         5.8         9.3        16.6        59.3     :
           : T)                                                                    :
           : M)                                                                    :
    7      :     6.9       5.2         6.4        10.1        18.2        66.2     :
           : T)                                                                    :
           : M)                                                                    :
    9      :     8.4       5.9         7.0        10.9        19.7        72.4     :
           : T)                                                         73.5(  9.3) :
           : M)                                                                    :
   12      :    10.6       7.0         7.7        11.9        21.4        82.7     :
           : T)                                                                    :
           : M)                                                                    :
   15      :    12.7       8.1         8.4        12.7        23.1                 :
           : T)                                                                    :
           : M)                                                                    :
   20      :    16.2       9.9         9.6        14.1        25.4                 :
           : T)                                              27.5( 24.5)           :
           : M)                                                                    :
   25      :    19.6      11.7        10.7        15.6        27.8                 :
           : T)                                                                    :
           : M)                                                                    :
   33      :    24.6      14.4        12.5        17.6        31.7                 :
           : T) 25.8( 35.4)                    18.9( 37.8)                         :
           : M)                                                                    :
   42      :    29.4      17.4        14.4        20.1                             :
           : T)         18.6( 46.3) 15.9( 48.6)                                    :
           : M)                                                                    :
   54      :              21.0        17.3        24.2                             :
           : T)                                                                    :
           : M)                                                                    :
   70      :                          22.8                                         :
           : T)                                                                    :
           : M)                                                                    :
           ------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  50.6( 51.5)  34.8( 68.1)  26.9( 73.2)  27.2( 59.1)  37.4( 39.8) 101.0( 15.0)
```

TABLE 8

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                   DENSIMETRIC FROUDE NUMBER

                    1            3            10            30           100          1000
RISE(DIA)  ----------------------------------------------------------------------------------
           : T)                                                                              :
           : M)              2.1[  0.4]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]  :
    1      :       1.9          2.6          4.0          6.3         10.9         36.5      :
           : T)                                                                              :
           : M]                                                                              :
    2      :       2.7          3.2          4.6          7.4         13.0         44.3      :
           : T)                                                                              :
           : M]                                                                              :
    3      :       3.6          3.6          5.1          8.1         14.4         49.8      :
           : T)                                                                              :
           : M]  4.3[  3.7]                                                                  :
    4      :       4.5          4.0          5.5          8.7         15.6         54.5      :
           : T)                                                                              :
           : M]                                                                              :
    5      :       5.4          4.4          5.8          9.3         16.6         58.0      :
           : T)                                                                              :
           : M]                                                                              :
    7      :       6.9          5.2          6.4         10.1         18.1         64.4      :
           : T)                                                                              :
           : M]                                                                              :
    9      :       8.5          6.0          6.9         10.9         19.4         69.5      :
           : T)                                                                              :
           : M]                                                                              :
   12      :      10.6          7.1          7.7         11.8         21.1         76.6      :
           : T)                                                                              :
           : M]                                                                              :
   15      :      12.8          8.2          8.4         12.6         22.6         82.3      :
           : T)                                                                              :
           : M]                                                                              :
   20      :      16.4         10.1          9.5         14.0         24.8         91.3      :
           : T)                                                                              :
           : M]                                                                              :
   25      :      20.1         11.9         10.6         15.2         26.7         99.4      :
           : T)                                                                 101.0( 26.5) :
           : M]                                                                              :
   33      :      25.8         14.8         12.4         17.1         29.6        112.0      :
           : T)                                                                              :
           : M]                                                                              :
   42      :      32.0         18.0         14.3         19.2         32.7        131.0      :
           : T)                                                                              :
           : M]                                                                              :
   54      :      39.9         22.3         16.8         21.9         36.7                    :
           : T)                                                    41.4( 68.8)               :
           : M]                                                                              :
   70      :      49.6         27.7         20.2         25.3         41.8                    :
           : T)  51.1( 72.6)                                                                 :
           : M]                                                                              :
   90      :      60.0         34.3         24.4         30.1         48.7                    :
           : T)              36.7( 96.7)  29.6(115.0)  31.9( 98.1)                           :
           : M]                                                                              :
  115      :                   41.5                      36.7                                :
           : T)                                                                              :
           : M]                                                                              :
  148      :                                37.9                                             :
           : T)                                                                              :
           : M]                                                                              :
           ----------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 117.0(105.0)  77.9(143.0)  58.3(167.0)  51.0(147.0)  58.0(109.0) 140.0( 43.3)
```

TABLE 9

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                  DENSIMETRIC FROUDE NUMBER

                       1            3            10           30           100          1000
RISE(DIA)   --------------------------------------------------------------------------------------
            : T)                                                                                 :
            : M]              2.1[  0.4]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]     :
    1       :         1.9          2.6          4.0          6.3         10.9         36.2       :
            : T)                                                                                 :
            : M]                                                                                 :
    2       :         2.7          3.2          4.6          7.4         13.0         44.3       :
            : T)                                                                                 :
            : M]                                                                                 :
    3       :         3.6          3.6          5.1          8.1         14.4         49.8       :
            : T)                                                                                 :
            : M]   4.3[  3.7]                                                                    :
    4       :         4.5          4.0          5.5          8.7         15.6         54.1       :
            : T)                                                                                 :
            : M]                                                                                 :
    5       :         5.4          4.4          5.8          9.3         16.4         58.0       :
            : T)                                                                                 :
            : M]                                                                                 :
    7       :         6.9          5.2          6.4         10.1         18.1         63.9       :
            : T)                                                                                 :
            : M]                                                                                 :
    9       :         8.5          6.0          6.9         10.8         19.4         69.0       :
            : T)                                                                                 :
            : M]                                                                                 :
   12       :        10.7          7.1          7.7         11.6         21.1         75.5       :
            : T)                                                                                 :
            : M]                                                                                 :
   15       :        12.9          8.2          8.4         12.6         22.5         80.8       :
            : T)                                                                                 :
            : M]                                                                                 :
   20       :        16.6         10.1          9.5         13.9         24.6         88.6       :
            : T)                                                                                 :
            : M]                                                                                 :
   25       :        20.2         11.9         10.6         15.1         26.5         95.4       :
            : T)                                                                                 :
            : M]                                                                                 :
   33       :        26.0         14.8         12.4         17.0         29.2        105.0       :
            : T)                                                                                 :
            : M]                                                                                 :
   42       :        32.7         18.2         14.3         18.9         32.2        113.0       :
            : T)                                                                                 :
            : M]                                                                                 :
   54       :        41.3         22.6         16.8         21.4         36.0        124.0       :
            : T)                                                                                 :
            : M]                                                                                 :
   70       :        52.7         28.4         20.2         24.6         40.4        136.0       :
                                                                                  151.0( 89.8)   :
            : T)                                                                                 :
            : M]                                                                                 :
   90       :        66.6         35.7         24.4         28.6         46.1        151.0       :
            : T)                                                                                 :
            : M]                                                                                 :
  115       :        83.1         44.6         29.4         33.5         53.0        170.0       :
            : T)                                                                                 :
            : M]                                                                                 :
  148       :       104.0         55.8         36.4         40.0         62.1                    :
            : T) 114.0(165.0)                                                                    :
            : M]                                                                                 :
  190       :       127.0         69.6         44.9         48.5         74.0                    :
                               81.4(229.0)                            77.7(204.0)                :
            : T)                                                                                 :
            : M]                                                                                 :
  244       :                      85.9         55.8         60.4         89.8                    :
            : T)                                64.0(285.0)  66.0(267.0)                          :
            : M]                                                                                 :
            --------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 185.0(239.0) 101.0(300.0)  67.3(300.0)  75.7(301.0) 108.0(300.0) 191.0(138.0)
```

TABLE 10

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.05

```
                                  DENSIMETRIC FROUDE NUMBER

                      1            3             10            30            100           1000
RISE(DIA)  ----------------------------------------------------------------------------------------
           : M]               2.1[  0.4]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   2.1[  0.0]   :
    1      :         1.9         2.6           4.0           6.3          10.9          36.2     :
           : M]                                                                                :
    2      :         2.7         3.2           4.6           7.4          13.0          44.3     :
           : M]                                                                                :
    3      :         3.6         3.6           5.1           8.1          14.4          49.8     :
           : M]   4.3[  3.7]                                                                   :
    4      :         4.5         4.0           5.5           8.7          15.6          54.1     :
           : M]                                                                                :
    5      :         5.4         4.4           5.8           9.3          16.4          58.0     :
           : M]                                                                                :
    7      :         6.9         5.2           6.4          10.1          18.1          63.9     :
           : M]                                                                                :
    9      :         8.5         6.0           6.9          10.8          19.4          69.0     :
           : M]                                                                                :
   12      :        10.7         7.1           7.7          11.8          21.1          75.0     :
           : M]                                                                                :
   15      :        12.9         8.2           8.4          12.6          22.5          80.8     :
           : M]                                                                                :
   20      :        16.6        10.1           9.5          13.9          24.6          88.2     :
           : M]                                                                                :
   25      :        20.2        11.9          10.6          15.1          26.5          94.5     :
           : M]                                                                                :
   33      :        26.2        14.9          12.4          16.9          29.2         103.0     :
           : M]                                                                                :
   42      :        32.7        18.2          14.3          18.9          32.7         112.0     :
           : M]                                                                                :
   54      :        41.6        22.6          16.8          21.4          35.7         121.0     :
           : M]                                                                                :
   70      :        53.0        28.6          20.2          24.6          40.3         132.0     :
           : M]                                                                                :
   90      :        68.1        36.0          24.4          28.4          45.7         144.0     :
           : M]                                                                                :
  115      :        86.3        45.2          29.6          33.1          52.2         156.0     :
           : M]                                                                                :
  148      :       110.0        57.5          36.5          39.1          60.9         172.0     :
           : M]                                                                                :
  190      :       141.0        73.0          45.1          46.8          71.3         189.0     :
           : M]                                                                                :
  244      :       180.0        92.7          56.3          56.5          84.8                   :
           : M]                                                                                :
           ----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 221.0(300.0) 113.0(301.0)  67.8(300.0)  66.5(301.0)  98.4(301.0) 201.0(221.0)
```

TABLE 11

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.02

```
                               DENSIMETRIC FROUDE NUMBER

                 1            3           10           30          100         1000
RISE(DIA)  ------------------------------------------------------------------------------
          : T)                                                                              :
          : M)                 2.1(  0.4)   2.0(  0.0)   2.0(  0.0)   2.0(  0.0)   2.0(  0.0) :
   1      :      1.9          2.6          3.8          5.8          9.7         27.8        :
          : T)                                                                              :
          : M)                                                                              :
   2      :      2.7          3.1          4.4          6.7         11.2         33.3        :
          : T)                                                                              :
          : M)                                                                              :
   3      :      3.6          3.5          4.8          7.4         12.4         37.2        :
          : T)                                                                              :
          : M)   4.2(  3.7)                                                                 :
   4      :      4.5          3.9          5.1          7.8         13.3         40.5        :
          : T)                                                                              :
          : M)                                                                              :
   5      :      5.3          4.3          5.4          8.3         13.9         43.4        :
          : T)                                                                45.5(  5.8)   :
          : M)                                                                              :
   7      :      6.8          5.0          6.0          8.9         15.2         48.8        :
          : T)                                                                              :
          : M)                                                                              :
   9      :      8.2          5.7          6.4          9.5         16.2         55.7        :
          : T)                                                                              :
          : M)                                                                              :
  12      :     10.3          6.7          7.0         10.3         17.6                      :
          : T)                                                   18.5( 14.2)                :
          : M)                                                                              :
  15      :     12.2          7.7          7.6         10.9         18.9                      :
          : T)                                                                              :
          : M)                                                                              :
  20      :     15.3          9.3          8.5         12.0         21.1                      :
          : T)  16.2( 21.8)                           12.2( 21.4)                             :
          : M)                                                                              :
  25      :     17.9         10.9          9.3         13.0                                   :
          : T)              11.6( 28.0)   9.9( 28.3)                                          :
          : M)                                                                              :
  33      :                  13.0         10.6         14.8                                   :
          : T)                                                                              :
          : M)                                                                              :
  42      :                  15.5         12.2                                                :
          : T)                                                                              :
          : M)                                                                              :
           ---------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  24.0( 32.1)  16.6( 42.2)  13.5( 45.1)  16.0( 35.2)  24.1( 23.2)  60.7(  9.5)
```

TABLE 12

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.02

```
                                 DENSIMETRIC FROUDE NUMBER

                    1            3            10           30           100          1000
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)                                                                                 
           : M]                2.1( 0.4)    2.0( 0.0)    2.0( 0.0)    2.0( 0.0)    2.0( 0.0)  :
    1      :        1.9          2.6          3.8          5.8          9.7          27.8      :
           : T)                                                                               :
           : M]                                                                               :
    2      :        2.7          3.1          4.4          6.7          11.2         33.1      :
           : T)                                                                               :
           : M]                                                                               :
    3      :        3.6          3.5          4.8          7.4          12.3         36.7      :
           : T)                                                                               :
           : M]   4.2( 3.7)                                                                   :
    4      :        4.5          3.9          5.1          7.8          13.2         39.6      :
           : T)                                                                               :
           : M]                                                                               :
    5      :        5.4          4.3          5.4          8.2          13.9         42.2      :
           : T)                                                                               :
           : M]                                                                               :
    7      :        6.9          5.0          6.0          8.9          15.0         46.5      :
           : T)                                                                               :
           : M]                                                                               :
    9      :        8.4          5.7          6.4          9.5          16.0         50.2      :
           : T)                                                                  55.3( 12.1)  :
           : M]                                                                               :
   12      :        10.4         6.8          7.0          10.2         17.3                  :
           : T)                                                                               :
           : M]                                                                               :
   15      :        12.6         7.8          7.6          10.8         18.2         60.4      :
           : T)                                                                               :
           : M]                                                                               :
   20      :        15.9         9.5          8.5          11.7         19.8                  :
           : T)                                                                               :
           : M]                                                                               :
   25      :        19.2         11.2         9.3          12.5         21.1                  :
           : T)                                                       22.3( 29.6)             :
           : M]                                                                               :
   33      :        23.9         13.7         10.6         13.6         23.2                  :
           : T)   25.5( 35.8)                                                                 :
           : M]                                                                               :
   42      :        28.6         16.5         12.0         14.9         25.8                  :
           : T)              18.0( 47.8)  13.8( 54.0)  15.1( 44.2)                            :
           : M]                                                                               :
   54      :                     19.7                      16.5                               :
           : T)                                                                               :
           : M]                                                                               :
   70      :                     23.5         16.2         19.5                               :
           : T)                                                                               :
           : M]                                                                               :
           -----------------------------------------------------------------------------------:
DIL AT MAX REAL
OR PERMITTED RISE  40.5( 52.2)  27.4( 70.8)  19.9( 83.6)  20.5( 71.6)  29.3( 48.4)  73.9( 19.6)
```

TABLE 13

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.02

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.1(0.4] 2.6	2.0(0.0] 3.8	2.0(0.0] 5.8	2.0(0.0] 9.7	2.0(0.0] 27.8
2	2.7	3.1	4.4	6.7	11.2	33.1
3	3.6	3.5	4.8	7.4	12.3	36.7
4	4.2(3.7] 4.5	3.9	5.1	7.8	13.2	39.4
5	5.4	4.3	5.4	8.2	13.8	41.9
7	6.9	5.0	5.9	8.9	15.0	45.9
9	8.4	5.7	6.4	9.5	15.9	49.1
12	10.5	6.8	7.0	10.1	17.0	53.0
15	12.6	7.8	7.6	10.7	18.0	56.8
20	16.2	9.6	8.5	11.6	19.4	61.8
25	19.7	11.3	9.3	12.3	20.5	66.4
33	25.3	14.0	10.7	13.4	22.2	72.9 74.5(35.4)
42	31.3	17.1	12.2	14.5	23.8	80.0
54	39.1	21.1	14.1	15.9	25.6	91.1
70	48.6 50.3(73.6)	26.2	16.7	17.6	28.0 30.3(87.0)	
90	58.4	32.2 35.4(102.0)	19.7	19.7	30.8	
115		38.9	23.4 25.3(129.0)	22.2 23.1(124.0)	34.4	
146		47.2	27.8	25.7		
190			34.7	32.6		
DIL AT MAX PEAL OR PERMITTED RISE	93.0(107.0)	61.3(149.0)	41.1(194.0)	34.5(194.0)	41.2(143.0)	101.0(58.2)

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.1[0.4] 2.6	2.0[0.0] 3.8	2.0[0.0] 5.9	2.0[0.0] 9.7	2.0[0.0] 27.8
2	2.7	3.1	4.4	6.7	11.2	33.1
3	3.6	3.5	4.8	7.4	12.3	36.5
4	4.2[3.7] 4.5	3.9	5.1	7.8	13.2	39.4
5	5.4	4.3	5.4	8.2	13.8	41.6
7	6.9	5.0	5.9	8.9	14.9	45.5
9	6.4	5.7	6.4	9.5	15.9	48.8
12	10.6	6.8	7.0	10.1	17.0	52.7
15	12.7	7.8	7.6	10.7	18.0	56.1
20	16.3	9.6	8.5	11.6	19.3	60.8
25	19.8	11.4	9.3	12.3	20.4	64.5
33	25.4	14.1	10.7	13.4	22.0	70.1
42	31.8	17.3	12.2	14.4	23.5	75.2
54	40.2	21.4	14.2	15.8	25.2	81.2
70	51.2	26.9	16.9	17.4	27.2	88.2
90	64.8	33.8	20.1	19.4	29.6	96.1
115	61.1	42.2	24.1	21.8	32.2	105.0 107.0(123.0)
146	101.0 112.0(167.0)	52.8	29.4	25.1	35.6	116.0
190	123.0	65.6 76.6(236.0)	35.9	29.0	39.7	134.0
244		80.9	43.9	34.0	45.0 49.6(289.0)	
DIL AT MAX REAL OR PERMITTED RISE	161.0(243.0)	93.8(300.0)	51.7(300.0)	39.1(301.0)	50.8(301.0)	140.0(199.0)

TABLE 15

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.02

```
                                   DENSIMETRIC FROUDE NUMBER

                      1             3              10              30              100             1000
RISE(DIA)  ----------------------------------------------------------------------------------------------------
           : M]               2.1[  0.4]    2.0[  0.0]     2.0[  0.0]      2.0[  0.0]      2.0[  0.0]   :
    1      :          1.9          2.6            3.8             5.8             9.7            27.8       :
           : M]                                                                                         :
    2      :          2.7          3.1            4.4             6.7            11.2            33.1       :
           : M]                                                                                         :
    3      :          3.6          3.5            4.8             7.4            12.3            36.5       :
           : M]   4.2[  3.7]                                                                            :
    4      :          4.5          3.9            5.1             7.8            13.2            39.4       :
           : M]                                                                                         :
    5      :          5.4          4.3            5.4             8.2            13.8            41.6       :
           : M]                                                                                         :
    7      :          6.9          5.0            5.9             8.9            14.9            45.5       :
           : M]                                                                                         :
    9      :          8.4          5.7            6.4             9.5            15.9            48.8       :
           : M]                                                                                         :
   12      :         10.6          6.8            7.0            10.1            17.0            52.7       :
           : M]                                                                                         :
   15      :         12.7          7.8            7.6            10.7            18.0            55.7       :
           : M]                                                                                         :
   20      :         16.3          9.6            8.5            11.6            19.3            60.5       :
           : M]                                                                                         :
   25      :         19.8         11.4            9.3            12.3            20.4            64.2       :
           : M]                                                                                         :
   33      :         25.6         14.1           10.7            13.4            22.0            69.5       :
           : M]                                                                                         :
   42      :         32.0         17.3           12.2            14.4            23.4            74.4       :
           : M]                                                                                         :
   54      :         40.5         21.5           14.2            15.7            25.1            80.0       :
           : M]                                                                                         :
   70      :         51.9         27.1           16.9            17.4            27.1            86.4       :
           : M]                                                                                         :
   90      :         66.2         34.0           20.2            19.4            29.2            93.1       :
           : M]                                                                                         :
  115      :         84.1         42.8           24.4            21.8            31.8           100.0       :
           : M]                                                                                         :
  148      :        108.0         54.3           29.8            25.0            35.1           109.0       :
           : M]                                                                                         :
  190      :        137.0         69.0           36.6            29.0            38.7           117.0       :
           : M]                                                                                         :
  244      :        175.0         87.7           45.6            34.0            43.3           128.0       :
           : M]                                                                                         :
           ----------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 215.0(301.0) 107.0(300.0)  54.7(301.0)  39.2(301.0)  47.9(302.0) 137.0(300.0)
```

TABLE 16

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                          1            3            10            30           100          1000
RISE(DIA)   ------------------------------------------------------------------------------------------
            : T)
            : M]                   2.1[  0.4]   2.0[  0.0]   2.0[  0.0]   2.0[  0.0]   2.0[  0.0]   :
    1       :        1.9           2.6          3.7          5.6          8.8          22.2          :
            : T)                                                                                     :
            : M]                                                                                     :
    2       :        2.7           3.0          4.2          6.3          10.1         25.4          :
            : T)                                                                                     :
            : M]                                                                                     :
    3       :        3.6           3.5          4.6          6.9          11.0         27.8          :
            : T)                                                                                     :
            : M]   4.2[  3.6]                                                                        :
    4       :        4.5           3.8          4.9          7.3          11.7         29.6          :
            : T)                                                                                     :
            : M]                                                                                     :
    5       :        5.3           4.2          5.2          7.6          12.3         31.1          :
            : T)                                                                                     :
            : M]                                                                                     :
    7       :        6.8           4.9          5.7          8.2          13.2         33.8          :
            : T)                                                                     34.0(  7.3)   :
            : M]                                                                                     :
    9       :        8.2           5.6          6.1          8.7          13.9         36.2          :
            : T)                                                                                     :
            : M]                                                                                     :
   12       :        10.2          6.6          6.6          9.3          14.9         40.8          :
            : T)                                                                                     :
            : M]                                                                                     :
   15       :        12.1          7.5          7.1          9.8          15.8                       :
            : T)                                                       15.9( 15.6)                   :
            : M]                                                                                     :
   20       :        15.1          9.0          8.0          10.6         17.0                       :
            : T)  16.1( 22.0)                             11.0( 23.2)                                :
            : M]                                                                                     :
   25       :        17.6          10.5         8.7          11.3         18.7                       :
            : T)               11.3( 28.4)  9.3( 29.4)                                               :
            : M]                                                                                     :
   33       :                      12.5         9.8          12.4                                    :
            : T)                                                                                     :
            : M]                                                                                     :
   42       :                      14.1         10.8                                                 :
            : T)                                                                                     :
            : M]                                                                                     :
            ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  20.1( 32.3)  14.2( 43.2)  11.6( 47.8)  13.8( 38.8)  19.9( 26.7)  42.8( 12.4)
```

TABLE 17

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.00

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	: T)						
	: M)		2.1(0.4)	2.0(0.0)	2.0(0.0)	2.0(0.0)	2.0(0.0)
1	:	1.9	2.6	3.7	5.6	8.8	22.2
	: T)						
	: M)						
2	:	2.7	3.0	4.2	6.3	10.1	25.4
	: T)						
	: M)						
3	:	3.6	3.5	4.6	6.9	11.0	27.7
	: T)						
	: M)	4.2(3.6)					
4	:	4.5	3.8	4.9	7.3	11.6	29.2
	: T)						
	: M)						
5	:	5.4	4.2	5.2	7.6	12.2	30.7
	: T)						
	: M)						
7	:	6.8	4.9	5.6	8.2	13.1	32.9
	: T)						
	: M)						
9	:	8.3	5.6	6.1	8.6	13.7	34.8
	: T)						
	: M)						
12	:	10.3	6.6	6.6	9.2	14.6	37.2
	: T)						
	: M)						
15	:	12.4	7.6	7.1	9.7	15.3	39.3
	: T)						39.8(15.8)
	: M)						
20	:	15.7	9.2	8.0	10.4	16.4	42.6
	: T)						
	: M)						
25	:	18.9	10.8	8.7	11.1	17.3	46.5
	: T)						
	: M)						
33	:	23.6	13.3	9.9	12.0	18.5	
	: T)	25.1(35.9)				18.6(33.8)	
	: M)						
42	:	28.2	15.9	11.2	12.8	19.8	
	: T)		17.5(48.4)		13.5(48.9)		
	: M)						
54	:		18.9	12.7	14.0	21.9	
	: T)			13.0(56.5)			
	: M)						
70	:		21.8	14.6	15.3		
	: T)						
	: M)						
DIL AT MAX PEAK OR PERMITTED RISE		31.5(52.6)	22.0(72.5)	16.3(89.0)	16.8(80.4)	23.3(57.1)	49.7(26.7)

TABLE 18

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.00

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	T)						
	M)		2.1[0.4]	2.0[0.0]	2.0[0.0]	2.0[0.0]	2.0[0.0]
1		1.9	2.6	3.7	5.6	8.8	22.0
	T)						
	M)						
2		2.7	3.0	4.2	6.3	10.1	25.4
	T)						
	M)						
3		3.6	3.5	4.6	6.9	11.0	27.5
	T)						
	M)	4.2[3.7]					
4		4.5	3.8	4.9	7.3	11.6	29.2
	T)						
	M)						
5		5.4	4.2	5.2	7.6	12.1	30.5
	T)						
	M)						
7		6.8	4.9	5.6	8.2	13.0	32.7
	T)						
	M)						
9		8.3	5.6	6.0	8.6	13.7	34.3
	T)						
	M)						
12		10.4	6.6	6.6	9.2	14.5	36.5
	T)						
	M)						
15		12.6	7.6	7.1	9.7	15.2	38.2
	T)						
	M)						
20		16.0	9.3	8.0	10.3	16.2	40.6
	T)						
	M)						
25		19.4	10.9	8.8	10.9	16.9	42.6
	T)						
	M)						
33		24.9	13.6	10.0	11.8	18.0	45.2
	T)						
	M)						
42		30.7	16.6	11.3	12.7	19.1	47.9
	T)						49.9(49.4)
	M)						
54		38.3	20.4	13.1	13.7	20.2	51.2
	T)						
	M)						
70		47.7	25.3	15.3	15.0	21.5	55.4
	T)	49.9(74.4)					
	M)						
90		57.3	31.1	18.1	16.6	22.9	
	T)		34.6(104.0)			23.9(104.0)	
	M)						
115			37.3	21.4	18.4	24.6	
	T)			23.9(136.0)	19.8(138.0)		
	M)						
148			43.2	25.2	20.5	26.7	
	T)						
	M)						
190				29.0	22.9		
	T)						
	M)						
DIL AT MAX REAL OR PERMITTED RISE		62.5(108.0)	43.4(153.0)	29.9(207.0)	24.9(225.0)	30.0(178.0)	62.7(84.6)

TABLE 19

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                        1            3            10            30            100           1000
RISE(DIA)  ---------------------------------------------------------------------------------------------
           : T)                                                                                         :
           : M]                  2.1[  0.4]   2.0[  0.0]   2.0[  0.0]   2.0[  0.0]    2.0[  0.0]        :
    1      :           1.9          2.6          3.7          5.6          8.8         22.0             :
           : T)                                                                                         :
           : M]                                                                                         :
    2      :           2.7          3.0          4.2          6.3         10.1         25.3             :
           : T)                                                                                         :
           : M]                                                                                         :
    3      :           3.6          3.5          4.6          6.9         11.0         27.5             :
           : T)                                                                                         :
           : M]      4.2[  3.7]                                                                         :
    4      :           4.5          3.8          4.9          7.3         11.6         29.0             :
           : T)                                                                                         :
           : M]                                                                                         :
    5      :           5.4          4.2          5.2          7.6         12.1         30.5             :
           : T)                                                                                         :
           : M]                                                                                         :
    7      :           6.9          4.9          5.6          8.2         13.0         32.7             :
           : T)                                                                                         :
           : M]                                                                                         :
    9      :           8.3          5.6          6.0          8.6         13.6         34.3             :
           : T)                                                                                         :
           : M]                                                                                         :
   12      :          10.5          6.6          6.6          9.2         14.5         36.2             :
           : T)                                                                                         :
           : M]                                                                                         :
   15      :          12.6          7.6          7.1          9.7         15.1         38.0             :
           : T)                                                                                         :
           : M]                                                                                         :
   20      :          16.1          9.3          8.0         10.3         16.1         40.2             :
           : T)                                                                                         :
           : M]                                                                                         :
   25      :          19.6         11.0          8.8         10.9         16.9         42.0             :
           : T)                                                                                         :
           : M]                                                                                         :
   33      :          25.1         13.7         10.0         11.8         17.9         44.5             :
           : T)                                                                                         :
           : M]                                                                                         :
   42      :          31.3         16.7         11.4         12.6         18.9         46.8             :
           : T)                                                                                         :
           : M]                                                                                         :
   54      :          39.6         20.7         13.2         13.7         19.9         49.2             :
           : T)                                                                                         :
           : M]                                                                                         :
   70      :          50.5         26.0         15.6         15.0         21.2         52.0             :
           : T)                                                                                         :
           : M]                                                                                         :
   90      :          63.9         32.7         19.5         16.7         22.5         54.8             :
           : T)                                                                                         :
           : M]                                                                                         :
  115      :          79.7         40.8         22.3         18.5         23.9         58.0             :
           : T)                                                                                         :
           : M]                                                                                         :
  146      :          99.6         50.9         27.1         20.9         25.6         61.5             :
           : T)  111.0(169.0)                                                     65.1(187.0)           :
           : M]                                                                                         :
  190      :         121.0         63.4         32.9         23.9         27.5         65.4             :
           : T)                 76.9(240.0)                                                             :
           : M]                                                                                         :
  244      :         139.0         77.8         40.2         27.6         29.8         70.3             :
           : T)                                                                                         :
           : M]                                                                                         :
           ---------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 139.0(245.0)  90.2(300.0)  47.4(300.0)  31.7(301.0)  31.9(302.0)  76.2(300.0)
```

TABLE 20

DIFFUSER PLUME DILUTION
PORT SPACING = 2 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.00

		DENSIMETRIC FROUDE NUMBER					
RISE(DIA)		1	3	10	30	100	1000
	M]		2.1(0.4)	2.0(0.0)	2.0(0.0)	2.0(0.0)	2.0(0.0)
1		1.9	2.6	3.7	5.6	8.8	22.0
	M]						
2		2.7	3.0	4.7	6.3	10.1	25.3
	M]						
3		3.6	3.5	4.6	6.9	11.0	27.5
	M]	4.2(3.7)					
4		4.5	3.8	4.9	7.3	11.6	29.0
	M]						
5		5.4	4.2	5.2	7.6	12.1	30.5
	M]						
7		6.9	4.9	5.6	8.2	13.0	32.7
	M]						
9		8.3	5.6	6.0	8.6	13.6	34.3
	M]						
12		10.5	6.6	6.6	9.2	14.5	36.2
	M]						
15		12.6	7.6	7.1	9.7	15.1	38.0
	M]						
20		16.1	9.3	8.0	10.3	16.1	40.2
	M]						
25		19.6	11.0	8.8	10.9	16.9	42.0
	M]						
33		25.3	13.7	10.0	11.8	17.9	44.4
	M]						
42		31.5	16.8	11.4	12.6	18.9	46.5
	M]						
54		39.9	20.8	13.2	13.7	19.9	48.9
	M]						
70		51.2	26.2	15.7	15.0	21.1	51.5
	M]						
90		65.3	32.9	18.6	16.7	22.4	54.2
	M]						
115		82.5	41.3	22.5	18.5	23.8	56.9
	M]						
148		106.0	52.5	27.5	21.0	25.5	59.9
	M]						
190		135.0	66.6	33.8	24.1	27.3	63.0
	M]						
244		173.0	84.7	41.8	28.1	29.5	66.2
	M]						
DIL AT MAX REAL OR PERMITTED RISE		212.0(301.0)	103.0(301.0)	50.2(301.0)	32.1(301.0)	31.7(301.0)	69.1(301.0)

TABLE 21

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.10

```
                                     DENSIMETRIC FROUDE NUMBER

                          1           3            10           30           100         1000
RISE(DIA)  ------------------------------------------------------------------------------------------
           : T)                                                                                    :
           : M]                                6.3[  1.0]   6.2[  0.1]   6.2[  0.0]   6.2[  0.0]   :
    1      :             1.9          2.8          6.4         11.8         22.2         85.6       :
           : T)                                                                                    :
           : M]                                                                                    :
    2      :             2.7          3.7          8.2         14.4         27.3        110.0       :
           : T)                                                                      117.0(  2.4)  :
           : M]                                                                                    :
    3      :             3.5          4.6          9.6         16.4         31.1        131.0       :
           : T)                                                                                    :
           : M]                                                                                    :
    4      :             4.5          5.6         10.9         18.2         34.3                    :
           : T)                                                                                    :
           : M]                                                                                    :
    5      :             5.6          6.6         12.0         20.0         37.3                    :
           : T)                                                          41.6(  6.6)               :
           : M]                                                                                    :
    7      :             8.1          8.8         14.4         23.3         42.8                    :
           : T)                                                                                    :
           : M]                    9.1[  7.3]                                                      :
    9      :            10.8         11.0         16.8         26.3         48.5                    :
           : T)                                             28.4( 10.3)                            :
           : M]                                                                                    :
   12      :            15.4         14.0         20.4         31.3                                 :
           : T)                                23.1( 14.2)                                         :
           : M]    18.1[ 13.7]                                                                     :
   15      :            20.3         17.0         24.4         36.7                                 :
           : T)    23.9( 17.7)  20.4( 18.3)                                                        :
           : M]                                                                                    :
   20      :            26.9         22.5         33.1                                              :
           : T)                                                                                    :
           : M]                                                                                    :
   25      :                         34.1                                                           :
           : T)                                                                                    :
           : M]                                                                                    :
           ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  52.7( 24.4)  41.3( 25.6)  35.9( 20.8)  40.0( 16.0)  57.5( 10.6) 163.0(  3.8)
```

TABLE 22

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.10

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	: T)						
	: M)			6.3(1.0)	6.2(0.1)	6.2(0.0)	6.2(0.0)
1	:	1.9	2.8	6.4	11.7	22.2	85.0
	: T)						
	: M)						
2	:	2.7	3.7	8.2	14.3	27.1	107.0
	: T)						
	: M)						
3	:	3.6	4.6	9.6	16.3	30.9	123.0
	: T)						
	: M)						
4	:	4.5	5.6	10.8	18.1	33.8	137.0
	: T)						146.0(4.7)
	: M)						
5	:	5.6	6.6	12.0	19.8	36.5	150.0
	: T)						
	: M)						
7	:	8.1	8.8	14.2	22.9	41.3	180.0
	: T)						
	: M)		9.3(7.5)				
9	:	10.9	10.9	16.4	26.0	45.9	
	: T)						
	: M)						
12	:	15.6	14.0	19.7	30.3	51.9	
	: T)					54.2(13.1)	
	: M)	19.6(14.3)					
15	:	20.8	17.0	23.1	34.8	58.4	
	: T)				40.5(19.1)		
	: M)						
20	:	28.2	21.9	28.8	41.9	70.5	
	: T)			35.0(24.9)			
	: M)						
25	:	35.0	26.7	35.2	49.8		
	: T)	37.8(27.3)	31.8(30.0)				
	: M)						
33	:	44.9	35.3	48.8			
	: T)						
	: M)						
DIL AT MAX REAL OR PERMITTED RISE		87.4(37.9)	68.4(41.7)	56.6(35.8)	58.1(29.1)	75.2(20.7)	204.0(7.6)

TABLE 23

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                  DENSIMETRIC FROUDE NUMBER

                      1           3          10          30        100         1000
RISE(DIA)   ------------------------------------------------------------------------------
            : T)                                                                         :
            : M]                          6.3[ 1.0]   6.2[ 0.1]  6.2[ 0.0]   6.2[ 0.0]   :
      1     :       1.9         2.8         6.4        11.7       22.0        84.4       :
            : T)                                                                         :
            : M]                                                                         :
      2     :       2.7         3.7         8.2        14.3       27.1       105.0       :
            : T)                                                                         :
            : M]                                                                         :
      3     :       3.6         4.6         9.5        16.3       30.7       120.0       :
            : T)                                                                         :
            : M]                                                                         :
      4     :       4.5         5.6        10.8        18.1       33.6       132.0       :
            : T)                                                                         :
            : M]                                                                         :
      5     :       5.6         6.6        12.0        19.7       36.2       143.0       :
            : T)                                                                         :
            : M]                                                                         :
      7     :       8.1         8.7        14.2        22.8       40.8       161.0       :
            : T)                                                                         :
            : M]              9.4[ 7.6]                                                  :
      9     :      10.9        10.9        16.3        25.8       44.9       176.0       :
            : T)                                                                         :
            : M]                                                                         :
     12     :      15.7        14.0        19.4        30.0       50.5       197.0       :
            : T)                                                           206.0( 13.3)  :
            : M] 20.2[ 14.6]                                                             :
     15     :      21.0        17.0        22.5        34.0       56.1       217.0       :
            : T)                                                                         :
            : M]                                                                         :
     20     :      28.8        21.8        27.7        40.8       64.4       257.0       :
            : T)                                                                         :
            : M]                                                                         :
     25     :      36.2        26.7        32.7        47.5       73.0                   :
            : T)                                                                         :
            : M]                                                                         :
     33     :      47.5        34.3        41.0        58.4       85.7                   :
            : T)                                                88.1( 34.6)              :
            : M]                                                                         :
     42     :      59.7        42.8        51.2        70.5      101.0                   :
            : T) 74.0( 53.2)                         75.4( 45.6)                         :
            : M]                                                                         :
     54     :      75.2        54.5        66.2        87.8                              :
            : T)             62.6( 62.3) 68.1( 55.4)                                     :
            : M]                                                                         :
     70     :      95.2        71.5        93.7                                          :
            : T)                                                                         :
            : M]                                                                         :
            ------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 181.0( 75.0) 143.0( 85.9) 114.0( 77.5) 109.0( 66.7) 123.0( 53.1) 288.0( 21.5)
```

TABLE 24

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.10

		DENSIMETRIC FROUDE NUMBER					
RISE(DIA)		1	3	10	30	100	1000
	T) M]						
1	T) M]	1.9	2.8	6.3[1.0] 6.4	6.2[0.1] 11.7	6.2[0.0] 22.0	6.2[0.0] 84.4
2	T) M]	2.7	3.7	8.2	14.3	27.1	105.0
3	T) M]	3.6	4.6	9.5	16.3	30.7	119.0
4	T) M]	4.5	5.6	10.8	18.1	33.6	131.0
5	T) M]	5.6	6.6	12.0	19.7	36.2	141.0
7	T) M]	8.1	8.7	14.1	22.8	40.8	157.0
9	T) M]	10.9	9.5[7.7] 10.9	16.3	25.6	44.9	171.0
12	T) M]	15.7	14.0	19.4	29.8	50.5	189.0
15	T) M]	20.4[14.7] 21.1	17.0	22.5	34.0	55.7	204.0
20	T) M]	29.0	21.8	27.5	40.5	63.9	227.0
25	T) M]	36.5	26.7	32.2	47.1	71.9	247.0
33	T) M]	48.5	34.3	40.2	57.6	84.4	276.0
42	T) M]	61.3	42.8	48.8	69.0	97.5	305.0
54	T) M]	78.7	54.2	60.9	84.4	115.0	312.0(44.2) 345.0
70	T) M]	101.0	69.5	77.1	105.0	138.0	
90	T) M]	128.0	88.2	98.6	131.0	166.0	
115	T) M]	160.0	112.0	128.0	162.0(113.0) 165.0	173.0(95.3) 202.0	
146	T) M]	164.0(118.0) 200.0	138.0(142.0) 145.0	152.0(132.0) 177.0	212.0		
190	T) M]		241.0				
DIL AT MAX REAL OR PERMITTED RISE		257.0(166.0)	318.0(195.0)	256.0(191.0)	232.0(161.0)	237.0(139.0)	351.0(55.8)

TABLE 25

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.10

RISE(DIA)		DENSIMETRIC FROUDE NUMBER 1	3	10	30	100	1000
	M]			6.3[1.0]	6.2[0.1]	6.2[0.0]	6.2[0.0]
1		1.9	2.8	6.4	11.7	22.0	84.4
	M]						
2		2.7	3.7	8.2	14.3	27.1	105.0
	M]						
3		3.6	4.6	9.5	16.3	30.7	119.0
	M]						
4		4.5	5.6	10.8	18.0	33.6	131.0
	M]						
5		5.6	6.6	12.0	19.7	36.2	141.0
	M]						
7		8.1	8.7	14.1	22.8	40.8	157.0
	M]		9.5[7.7]				
9		10.9	10.9	16.3	25.6	44.6	170.0
	M]						
12		15.7	14.0	19.4	29.8	50.2	188.0
	M]	20.5[14.7]					
15		21.1	17.0	22.3	33.9	55.7	203.0
	M]						
20		29.0	21.8	27.3	40.5	63.9	223.0
	M]						
25		36.7	26.7	32.2	47.1	71.4	242.0
	M]						
33		48.5	34.3	39.9	57.2	83.8	267.0
	M]						
42		61.8	42.8	48.5	68.5	96.7	291.0
	M]						
54		79.3	54.1	60.1	83.8	114.0	320.0
	M]						
70		103.0	69.5	75.0	104.0	136.0	355.0
	M]						
90		132.0	88.2	93.8	128.0	164.0	
	M]						
115		169.0	112.0	117.0	159.0	198.0	
	M]						
148		216.0	143.0	149.0	200.0	242.0	
	M]						
190		277.0	183.0	188.0	251.0	297.0	
	M]						
244			234.0	239.0			
	M]						
DIL AT MAX RISE OR PERMITTED RISE		333.0(228.0)	286.0(299.0)	284.0(294.0)	312.0(240.0)	315.0(204.0)	362.0(73.4)

TABLE 26

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.05

```
                                          DENSIMETRIC FROUDE NUMBER

                          1             3             10            30            100           1000
RISE(DIA)   -----------------------------------------------------------------------------------------------
            : T)
            : M]                                  5.7[  0.9]   5.6[  0.1]   5.6[  0.0]    5.6[  0.0]   :
    1       :            1.9           2.8          5.8           9.9          17.6          62.2       :
            : T)                                                                                        :
            : M]                                                                                        :
    2       :            2.7           3.6          7.1          11.8          21.3          77.6       :
            : T)                                                                                        :
            : M]                                                                               90.4(  3.0)  :
    3       :            3.6           4.4          8.0          13.2          23.9                     :
            : T)                                                                                        :
            : M]                                                                                        :
    4       :            4.6           5.1          8.7          14.2          26.0         103.0       :
            : T)                                                                                        :
            : M]                                                                                        :
    5       :            5.6           6.0          9.4          15.2          28.0                     :
            : T)                                                                                        :
            : M]                                                                                        :
    7       :            8.1           7.6         10.6          16.9          31.3                     :
            : T)                                                               33.1(  8.1)              :
            : M]                    9.2[  8.9]                                                          :
    9       :           10.8           9.4         11.8          18.6          34.5                     :
            : T)                                                                                        :
            : M]                                                                                        :
   12       :           15.4          11.7         13.5          21.0          40.2                     :
            : T)                                             21.6( 12.8)                                :
            : M]  18.0[ 13.7]                                                                           :
   15       :           20.0          13.8         15.1          23.4                                   :
            : T)  23.4( 17.9)                   16.7( 17.7)                                             :
            : M]                                                                                        :
   20       :           25.6          17.2         18.3          28.6                                   :
            : T)                    17.3( 20.3)                                                         :
            : M]                                                                                        :
   25       :                         20.4         22.3                                                 :
            : T)                                                                                        :
            : M]                                                                                        :
            -----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  44.2( 25.0)  31.1( 29.6)  26.3( 27.1)  29.9( 20.4)  45.1( 13.2) 124.0(  4.9)
```

TABLE 27

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.05

```
                                         DENSIMETRIC FROUDE NUMBER

                         1                 3                10                30               100              1000
RISE(DIA)  -------------------------------------------------------------------------------------------------------------------
           : T)                                                                                                              :
           : M)                                          5.7[  0.9]        5.6[  0.1]        5.6[  0.0]        5.6[  0.0] :
    1      :            1.9               2.8               5.8               9.9              17.6              61.8        :
           : T)                                                                                                              :
           : M)                                                                                                              :
    2      :            2.7               3.6               7.1              11.8              21.3              76.6        :
           : T)                                                                                                              :
           : M)                                                                                                              :
    3      :            3.6               4.4               8.0              13.1              23.7              87.4        :
           : T)                                                                                                              :
           : M)                                                                                                              :
    4      :            4.6               5.1               8.7              14.1              25.8              96.3        :
           : T)                                                                                                              :
           : M)                                                                                                              :
    5      :            5.7               6.0               9.3              15.1              27.7             104.0        :
           : T)                                                                                            112.0(  6.1) :
           : M)                                                                                                              :
    7      :            8.1               7.6              10.6              16.8              30.7             119.0        :
           : T)                                                                                                              :
           : M)                                                                                                              :
    9      :           10.9               9.4              11.6              18.2              33.3             137.0        :
           : T)                                                                                                              :
           : M)                          9.5[  9.1]                                                                          :
   12      :           15.5              11.8              13.3              20.4              36.7                          :
           : T)                                                                                                              :
           : M)       19.4[ 14.3]                                                                                            :
   15      :           20.7              14.0              14.8              22.5              40.2                          :
           : T)                                                                         41.6( 16.4)                          :
           : M)                                                                                                              :
   20      :           27.5              17.5              17.4              25.8              45.8                          :
           : T)                                                       29.2( 25.0)                                            :
           : M)                                                                                                              :
   25      :           33.6              21.0              20.0              29.4              52.6                          :
           : T)       36.2( 27.5)                        24.1( 32.7)                                                         :
           : M)                                                                                                              :
   33      :           41.8              26.0              24.2              35.5                                            :
           : T)                         26.5( 33.9)                                                                          :
           : M)                                                                                                              :
   42      :                             31.8              30.5                                                              :
           : T)                                                                                                              :
           : M)                                                                                                              :
           -------------------------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  74.4( 39.0)  52.7( 48.9)  42.0( 48.7)  42.4( 38.7)  57.2( 26.4) 154.0(  9.8)
```

TABLE 28

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.05

```
                            DENSIMETRIC FROUDE NUMBER

                    1            3           10           30          100         1000
RISE(DIA) -------------------------------------------------------------------------------------
          : T)
          : M)                            5.7[  0.9]   5.6[  0.1]   5.6[  0.0]   5.6[  0.0]   :
    1     :        1.9          2.8          5.8          9.9         17.6         61.8       :
          : T)                                                                                :
          : M)                                                                                :
    2     :        2.7          3.6          7.1         11.8         21.1         76.0       :
          : T)                                                                                :
          : M)                                                                                :
    3     :        3.6          4.4          8.0         13.1         23.6         86.1       :
          : T)                                                                                :
          : M)                                                                                :
    4     :        4.6          5.1          8.7         14.1         25.6         93.6       :
          : T)                                                                                :
          : M)                                                                                :
    5     :        5.7          6.0          9.3         15.0         27.5        101.0       :
          : T)                                                                                :
          : M)                                                                                :
    7     :        8.1          7.6         10.5         16.7         30.3        112.0       :
          : T)                                                                                :
          : M)                                                                                :
    9     :       10.9          9.4         11.6         18.1         32.7        123.0       :
          : T)                                                                                :
          : M)               9.6[  9.3]                                                       :
   12     :       15.6         11.9         13.2         20.2         36.0        136.0       :
          : T)                                                                                :
          : M)  20.1[ 14.6]                                                                   :
   15     :       21.0         14.1         14.7         22.2         39.1        147.0       :
          : T)                                                                 156.0( 17.5) :
          : M)                                                                                :
   20     :       28.4         17.8         17.1         25.3         43.7        166.0       :
          : T)                                                                                :
          : M)                                                                                :
   25     :       35.2         21.3         19.6         28.2         48.1        187.0       :
          : T)                                                                                :
          : M)                                                                                :
   33     :       45.9         26.9         23.4         32.9         54.5                    :
          : T)                                                                                :
          : M)                                                                                :
   42     :       56.8         33.1         27.8         38.3         62.0                    :
          : T)                                                      64.3( 44.9)               :
          : M)                                                                                :
   54     :       70.7         41.0         33.6         45.5         72.1                    :
          : T)  71.0( 54.5)                            51.6( 63.4)                            :
          : M)                                                                                :
   70     :       85.6         51.0         41.6         56.3         88.2                    :
          : T)               51.6( 71.1)  45.2( 77.2)                                         :
          : M)                                                                                :
   90     :                    63.2         53.1         74.4                                 :
          : T)                                                                                :
          : M)                                                                                :
          -------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 160.0( 77.9) 116.0(102.0)  89.7(110.0)  79.4( 93.6)  90.3( 70.6) 216.0( 28.2)
```

TABLE 29

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                   DENSIMETRIC FROUDE NUMBER

                           1           3          10          30         100        1000
RISE(DIA)   ------------------------------------------------------------------------------------
            : T)                                                                               :
            : M]                                 5.7[  0.9]  5.6[  0.1] 5.6[  0.0]  5.6[  0.0] :
     1      :            1.9         2.8         5.8         9.9        17.6        61.8       :
            : T)                                                                               :
            : M]                                                                               :
     2      :            2.7         3.6         7.1        11.8        21.1        75.5       :
            : T)                                                                               :
            : M]                                                                               :
     3      :            3.6         4.4         8.0        13.1        23.6        85.6       :
            : T)                                                                               :
            : M]                                                                               :
     4      :            4.6         5.1         8.7        14.1        25.6        93.6       :
            : T)                                                                               :
            : M]                                                                               :
     5      :            5.7         6.0         9.3        15.0        27.3       100.0       :
            : T)                                                                               :
            : M]                                                                               :
     7      :            8.1         7.6        10.5        16.7        30.3       111.0       :
            : T)                                                                               :
            : M]                                                                               :
     9      :           10.9         9.4        11.6        18.1        32.7       120.0       :
            : T)                                                                               :
            : M]                    9.7[  9.3]                                                 :
    12      :           15.7        11.9        13.2        20.1        35.7       132.0       :
            : T)                                                                               :
            : M]        20.4[ 14.7]                                                            :
    15      :           21.0        14.1        14.7        22.0        38.8       142.0       :
            : T)                                                                               :
            : M]                                                                               :
    20      :           28.6        17.9        17.1        25.1        43.1       157.0       :
            : T)                                                                               :
            : M]                                                                               :
    25      :           35.7        21.4        19.6        27.8        47.5       169.0       :
            : T)                                                                               :
            : M]                                                                               :
    33      :           46.8        27.1        23.4        32.4        53.8       187.0       :
            : T)                                                                               :
            : M]                                                                               :
    42      :           58.8        33.6        27.7        37.2        60.5       204.0       :
            : T)                                                                               :
            : M]                                                                               :
    54      :           75.0        41.9        33.1        43.7        69.4       226.0       :
            : T)                                                                   233.0( 58.3):
            : M]                                                                               :
    70      :           95.6        53.0        40.8        52.3        80.7       254.0       :
            : T)                                                                               :
            : M]                                                                               :
    90      :          120.0        66.5        49.8        62.9        94.9                   :
            : T)                                                                               :
            : M]                                                                               :
   115      :          150.0        83.4        61.6        76.9       113.0                   :
            : T) 156.0(121.0)                                          124.0(130.0)            :
            : M]                                                                               :
   148      :          162.0       101.0        77.3        97.0       137.0                   :
            : T)                  114.0(165.0) 98.0(190.0) 109.0(166.0)                        :
            : M]                                                                               :
   190      :                      129.0        98.3       127.0       169.0                   :
            : T)                                                                               :
            : M]                                                                               :
   244      :                                  140.0                                           :
            : T)                                                                               :
            : M]                                                                               :
            ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 209.0(173.0) 262.0(235.0) 214.0(265.0) 177.0(237.0) 175.0(196.0) 276.0( 81.1)
```

TABLE 30

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.05

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	: M]			5.7[0.9]	5.6[0.1]	5.6[0.0]	5.6[0.0]
1	:	1.9	2.8	5.8	9.9	17.6	61.8
	: M]						
2	:	2.7	3.6	7.1	11.8	21.1	75.5
	: M]						
3	:	3.6	4.4	8.0	13.1	23.6	85.6
	: M]						
4	:	4.6	5.1	8.7	14.1	25.6	93.0
	: M]						
5	:	5.7	6.0	9.3	15.0	27.3	99.6
	: M]						
7	:	8.1	7.6	10.5	16.7	30.3	111.0
	: M]						
9	:	10.9	9.4	11.6	18.1	32.7	120.0
	: M]		9.7[9.3]				
12	:	15.7	11.9	13.2	20.1	35.7	131.0
	: M]	20.4[14.7]					
15	:	21.0	14.1	14.6	22.0	38.8	141.0
	: M]						
20	:	28.6	17.9	17.1	25.1	43.1	155.0
	: M]						
25	:	35.7	21.4	19.6	27.8	47.1	166.0
	: M]						
33	:	47.1	27.3	23.3	32.2	53.4	183.0
	: M]						
42	:	59.3	33.6	27.5	37.0	60.1	198.0
	: M]						
54	:	76.0	42.2	33.1	43.4	69.0	216.0
	: M]						
70	:	98.3	53.4	40.5	51.2	80.7	237.0
	: M]						
90	:	125.0	67.6	49.8	61.5	93.7	260.0
	: M]						
115	:	160.0	85.5	61.5	73.6	110.0	
	: M]						
148	:	204.0	109.0	76.6	90.0	132.0	
	: M]						
190	:	262.0	138.0	95.7	110.0	159.0	
	: M]						
244	:		176.0	120.0	136.0	194.0	
	: M]						

DIL AT MAX REAL
OR PERMITTED RISE 325.0(237.0) 216.0(300.0) 146.0(301.0) 163.0(300.0) 229.0(300.0) 286.0(114.0)

TABLE 31

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.02

```
                            DENSIMETRIC FROUDE NUMBER

                      1           3          10          30         100        1000
RISE(DIA) --------------------------------------------------------------------------------
          : T)                                                                          :
          : M)                           5.3[  0.9]  5.3[  0.1]  5.3[  0.0]  5.3[  0.0] :
    1     :          1.9         2.7         5.5         6.9        14.7        44.6    :
          : T)                                                                          :
          : M)                                                                          :
    2     :          2.7         3.6         6.6        10.3        17.3        54.2    :
          : T)                                                                          :
          : M)                                                                          :
    3     :          3.6         4.3         7.3        11.2        19.0        60.9    :
          : T)                                                          67.1(  4.0) :
          : M)                                                                          :
    4     :          4.6         5.1         7.9        12.0        20.5        67.6    :
          : T)                                                                          :
          : M)                                                                          :
    5     :          5.7         5.9         8.4        12.7        21.7        73.5    :
          : T)                                                                          :
          : M)                                                                          :
    7     :          8.1         7.5         9.3        13.8        23.9                :
          : T)                                                                          :
          : M)               9.1[  8.9]                                                 :
    9     :         10.8         9.2        10.1        14.8        25.8                :
          : T)                                              26.5( 10.0)                 :
          : M)                                                                          :
   12     :         15.2        11.3        11.2        16.1        28.4                :
          : T)                                  17.4( 15.2)                             :
          : M)  18.0[ 11.7]                                                             :
   15     :         19.8        13.3        12.2                    31.8                :
          : T)  23.1( 17.8)             13.8( 20.1)                                     :
          : M)                                                                          :
   20     :         25.3        16.1                    19.6                            :
          : T)              16.5( 20.8)                                                 :
          : M)                                                                          :
   25     :         29.5        18.6        15.5                                        :
          : T)                                                                          :
          : M)                                                                          :
          ------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  35.8( 25.1)  24.2( 30.9)  19.4( 32.1)  23.0( 24.8)  34.9( 16.2)  90.3(  6.5)
```

TABLE 32

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.02

```
                                      DENSIMETRIC FROUDE NUMBER

                          1             3            10            30           100          1000
RISE(DIA)   -------------------------------------------------------------------------------------------
            : T)                                                                                      :
            : M]                                5.3[  0.9]    5.3[  0.1]    5.3[  0.0]    5.3[  0.0]  :
    1       :            1.9           2.7           5.5           8.8          14.7          44.3    :
            : T)                                                                                      :
            : M]                                                                                      :
    2       :            2.7           3.6           6.6          10.3          17.3          53.4    :
            : T)                                                                                      :
            : M]                                                                                      :
    3       :            3.6           4.3           7.3          11.2          19.0          59.7    :
            : T)                                                                                      :
            : M]                                                                                      :
    4       :            4.6           5.1           7.8          12.0          20.4          65.3    :
            : T)                                                                                      :
            : M]                                                                                      :
    5       :            5.7           5.9           8.4          12.6          21.5          69.5    :
            : T)                                                                                      :
            : M]                                                                                      :
    7       :            8.1           7.5           9.2          13.7          23.4          77.6    :
            : T)                                                                      82.1(  8.2)  :
            : M]                                                                                      :
    9       :           10.9           9.2          10.0          14.6          25.1          85.5    :
            : T)                                                                                      :
            : M]                      9.3[  9.2]                                                      :
   12       :           15.5          11.5          11.1          15.8          27.3          97.9    :
            : T)                                                                                      :
            : M]    19.4[ 14.3]                                                                       :
   15       :           20.5          13.6          12.1          16.9          29.0                  :
            : T)                                                                                      :
            : M]                                                                                      :
   20       :           27.3          16.7          13.7          18.5          32.0                  :
            : T)                                                      32.2( 20.6)                     :
            : M]                                                                                      :
   25       :           33.1          19.7          15.4          20.0          34.8                  :
            : T)    35.7( 27.6)                               21.7( 31.0)                             :
            : M]                                                                                      :
   33       :           40.9          24.3          17.8          22.5          41.0                  :
            : T)                  25.1( 34.9)   19.3( 38.4)                                           :
            : M]                                                                                      :
   42       :                         28.6          20.4          25.4                                :
            : T)                                                                                      :
            : M]                                                                                      :
   54       :                                       24.3                                              :
            : T)                                                                                      :
            : M]                                                                                      :
            -------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  60.6( 39.4)   40.2( 51.4)   29.2( 59.5)   30.0( 50.0)   42.7( 33.6)  111.0( 13.3)
```

TABLE 33

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATION = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	M]			5.3[0.9]	5.3[0.1]	5.3[0.0]	5.3[0.0]
1		1.9	2.7	5.5	8.8	14.7	44.3
2		2.7	3.6	6.6	10.3	17.3	53.0
3		3.6	4.3	7.3	11.2	18.9	59.3
4		4.6	5.1	7.8	12.0	20.2	64.4
5		5.7	5.9	8.4	12.6	21.4	68.5
7		8.1	7.5	9.2	13.6	23.3	75.5
9		10.9	9.2	10.0	14.5	24.7	80.9
	M]		9.5[9.3]				
12		15.6	11.6	11.1	15.7	26.7	88.3
	M]	20.1[14.6]					
15		20.8	13.6	12.1	16.7	28.4	95.2
20		28.2	17.0	13.7	18.1	30.9	105.0
	T)						112.0(23.8)
25		34.9	20.2	15.3	19.6	32.9	114.0
33		44.9	25.4	17.9	21.5	35.8	129.0
42		55.7	30.9	20.7	23.7	39.0	
54		68.8	38.0	24.2	26.5	43.1	
	T)	69.5(54.9)				44.8(59.7)	
70		82.8	47.0	29.0	30.2	48.4	
	T)		48.9(74.1)		33.8(85.4)		
90			56.3	34.5	35.0	56.3	
	T)			35.3(93.1)			
115				41.3	42.2		
DIL AT MAX REAL OR PERMITTED RISE		136.0(79.1)	90.1(108.0)	61.5(139.0)	52.7(133.0)	61.9(97.2)	152.0(39.0)

TABLE 34

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.02

		DENSIMETRIC FROUDE NUMBER					
RISE(DIA)		1	3	10	30	100	1000
	T) M]			5.3[0.9]	5.3[0.1]	5.3[0.0]	5.3[0.0]
1		1.9	2.7	5.5	8.8	14.7	44.3
	T) M]						
2		2.7	3.6	6.6	10.3	17.3	53.0
	T) M]						
3		3.6	4.3	7.3	11.2	18.9	59.3
	T) M]						
4		4.6	5.1	7.8	12.0	20.2	63.9
	T) M]						
5		5.7	5.9	8.4	12.6	21.4	68.1
	T) M]						
7		8.1	7.5	9.2	13.6	23.3	75.0
	T) M]						
9		10.9	9.2	10.0	14.5	24.7	80.4
	T) M]		9.5[9.3]				
12		15.6	11.6	11.1	15.7	26.7	87.2
	T) M]	20.2[14.6]					
15		21.0	13.7	12.1	16.7	28.2	93.1
	T) M]						
20		28.4	17.1	13.7	18.1	30.7	102.0
	T) M]						
25		35.2	20.4	15.5	19.4	32.7	109.0
	T) M]						
33		45.9	25.6	18.0	21.4	35.4	119.0
	T) M]						
42		57.6	31.5	20.8	23.4	38.1	128.0
	T) M]						
54		73.5	39.4	24.6	26.2	41.6	140.0
	T) M]						
70		93.0	49.5	29.6	29.6	46.0	153.0
	T) M]						163.0(81.6)
90		117.0	6 .7	35.7	33.7	51.2	170.0
	T) M]						
115		145.0	77.0	43.3	39.0	57.5	192.0
	T) M]	153.0(123.0)					
148		176.0	95.5	52.9	45.8	65.8	
	T) M]		108.0(171.0)				
190			117.0	64.7	54.4	76.8	
	T) M]			76.0(232.0)		77.2(192.0)	
244			139.0	79.2	65.7	92.8	
	T) M]				66.2(247.0)		

DIL AT MAX REAL
OR PERMITTED RISE 194.0(176.0) 191.0(249.0) 93.7(300.0) 79.2(300.0) 115.0(296.0) 201.0(124.0)

TABLE 35

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	M]			5.3[0.9]	5.3[0.1]	5.3[0.0]	5.3[0.0]
1		1.9	2.7	5.5	8.8	14.7	44.3
	M]						
2		2.7	3.6	6.6	10.3	17.3	53.0
	M]						
3		3.6	4.3	7.3	11.2	18.9	59.3
	M]						
4		4.6	5.1	7.8	12.0	20.2	63.9
	M]						
5		5.7	5.9	8.4	12.6	21.4	68.1
	M]						
7		8.1	7.5	9.2	13.6	23.3	74.5
	M]						
9		10.9	9.2	10.0	14.5	24.7	79.8
	M]		9.5[9.4]				
12		15.7	11.6	11.1	15.7	26.7	86.6
	M]	20.4[14.7]					
15		21.0	13.7	12.1	16.7	28.2	92.6
	M]						
20		28.4	17.1	13.7	18.1	30.5	101.0
	M]						
25		35.5	20.5	15.5	19.4	32.4	108.0
	M]						
33		46.2	25.8	18.0	21.4	35.2	117.0
	M]						
42		58.4	31.8	20.8	23.4	37.9	126.0
	M]						
54		74.0	39.6	24.6	26.2	41.5	136.0
	M]						
70		95.6	50.2	29.6	29.4	45.5	148.0
	M]						
90		122.0	63.1	36.0	33.6	50.5	160.0
	M]						
115		154.0	79.2	43.7	38.7	56.3	173.0
	M]						
148		198.0	101.0	54.1	45.4	63.6	189.0
	M]						
190		253.0	128.0	67.3	53.9	72.5	207.0
	M]						
244			163.0	83.9	64.5	83.4	
	M]						
DIL AT MAX REAL OR PERMITTED RISE		321.0(242.0)	200.0(300.0)	101.0(300.0)	75.7(301.0)	94.6(300.0)	208.0(194.0)

TABLE 36

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                        1           3           10          30          100         1000
RISE(DIA)   -----------------------------------------------------------------------------------------
            : T)
            : M]                           5.1[  0.9]  5.0[  0.1]  5.0[  0.0]  5.0[  0.0]   :
    1       :          1.9         2.7         5.3         8.2        12.9        32.0      :
            : T)                                                                            :
            : M]                                                                            :
    2       :          2.7         3.5         6.2         9.3        14.8        37.0      :
            : T)                                                                            :
            : M]                                                                            :
    3       :          3.6         4.3         6.9        10.1        16.0        40.5      :
            : T)                                                                            :
            : M]                                                                            :
    4       :          4.6         5.0         7.4        10.7        17.0        43.1      :
            : T)                                                                            :
            : M]                                                                            :
    5       :          5.7         5.8         7.8        11.2        17.9        45.5      :
            : T)                                                              46.5(  5.5)   :
            : M]                                                                            :
    7       :          8.1         7.4         8.6        12.1        19.2        50.2      :
            : T)                                                                            :
            : M]                9.0[  8.9]                                                  :
    9       :         10.8         9.1         9.3        12.8        20.4        56.2      :
            : T)                                                  21.7( 11.8)               :
            : M]                                                                            :
   12       :         15.2        11.2        10.3        13.7        21.9                  :
            : T)                                                                            :
            : M]   18.0[ 13.7]                                                              :
   15       :         19.8        13.0        11.1        14.6        23.4                  :
            : T)   23.1( 17.9)                          15.0( 16.9)                         :
            : M]                                                                            :
   20       :         25.1        15.7        12.5        15.9                              :
            : T)               16.1( 21.1) 12.8( 21.6)                                      :
            : M)                                                                            :
   25       :         28.3        17.9        13.6        17.2                              :
            : T)                                                                            :
            : M)                                                                            :
   33       :                                 15.4                                          :
            : T)                                                                            :
            : M]                                                                            :
            -----------------------------------------------------------------------------------------
DIL AT MAX REAL
OR PERMITTED RISE  28.3( 25.2)  19.8( 31.5)  16.0( 34.7)  18.8( 28.3)  27.0( 19.6)  58.0(  9.1)
```

TABLE 37

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.00

```
                                         DENSIMETRIC FROUDE NUMBER

                          1             3             10            30           100           1000
RISE(DIA)      --------------------------------------------------------------------------------------------
               : T)                                                                                       :
               : M]                               5.1[  0.9]    5.0[  0.1]    5.0[  0.0]    5.0[  0.0]    :
    1          :         1.9           2.7           5.3           8.2          12.9          32.0        :
               : T)                                                                                       :
               : M]                                                                                       :
    2          :         2.7           3.5           6.2           9.3          14.7          36.7        :
               : T)                                                                                       :
               : M]                                                                                       :
    3          :         3.6           4.3           6.9          10.1          16.0          39.9        :
               : T)                                                                                       :
               : M]                                                                                       :
    4          :         4.6           5.0           7.4          10.7          16.9          42.5        :
               : T)                                                                                       :
               : M]                                                                                       :
    5          :         5.7           5.8           7.8          11.2          17.7          44.6        :
               : T)                                                                                       :
               : M]                                                                                       :
    7          :         8.1           7.4           8.6          12.0          19.0          47.8        :
               : T)                                                                                       :
               : M]                                                                                       :
    9          :        10.9           9.1           9.3          12.7          20.0          50.8        :
               : T)                                                                         53.9( 11.6)   :
               : M]                  9.2[  9.1]                                                           :
   12          :        15.5          11.3          10.3          13.5          21.3          54.5        :
               : T)                                                                                       :
               : M]   19.3[ 14.2]                                                                         :
   15          :        20.5          13.3          11.2          14.3          22.5          58.2        :
               : T)                                                                                       :
               : M]                                                                                       :
   20          :        27.1          16.3          12.6          15.5          24.0                      :
               : T)                                                           25.2( 24.7)                 :
               : M]                                                                                       :
   25          :        32.9          19.2          13.9          16.4          25.4                      :
               : T)   35.5( 27.7)                                                                         :
               : M]                                                                                       :
   33          :        40.3          23.4          16.0          17.9          27.5                      :
               : T)                 24.4( 35.3)   17.8( 40.9)   18.2( 35.3)                               :
               : M]                                                                                       :
   42          :                      27.4          18.1          19.4                                    :
               : T)                                                                                       :
               : M]                                                                                       :
   54          :                                    20.5          21.4                                    :
               : T)                                                                                       :
               : M]                                                                                       :
               --------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  43.8( 39.6)   30.3( 52.6)   22.2( 64.8)   22.8( 58.9)   31.6( 41.9)   67.5( 19.6)
```

TABLE 38

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                        1             3             10            30            100           1000
RISE(DIA)    ---------------------------------------------------------------------------------------
             : T)                                                                                  :
             : M]                               5.1[  0.9]    5.0[  0.1]    5.0[  0.0]    5.0[  0.0]  :
    1        :         1.9           2.7           5.3           8.2          12.9          32.0     :
             : T)                                                                                  :
             : M]                                                                                  :
    2        :         2.7           3.5           6.2           9.3          14.7          36.7     :
             : T)                                                                                  :
             : M]                                                                                  :
    3        :         3.6           4.3           6.9          10.1          16.0          39.6     :
             : T)                                                                                  :
             : M]                                                                                  :
    4        :         4.6           5.0           7.4          10.7          16.9          42.2     :
             : T)                                                                                  :
             : M]                                                                                  :
    5        :         5.7           5.8           7.8          11.2          17.6          44.0     :
             : T)                                                                                  :
             : M]                                                                                  :
    7        :         8.1           7.4           8.6          12.0          18.9          47.1     :
             : T)                                                                                  :
             : M]                                                                                  :
    9        :        10.9           9.1           9.3          12.6          19.8          49.8     :
             : T)                                                                                  :
             : M]                   9.4[  9.3]                                                     :
   12        :        15.6          11.4          10.3          13.5          21.1          52.7     :
             : T)                                                                                  :
             : M]   20.1[ 14.6]                                                                    :
   15        :        20.8          13.5          11.2          14.2          22.2          55.4     :
             : T)                                                                                  :
             : M]                                                                                  :
   20        :        28.0          16.7          12.6          15.3          23.4          58.7     :
             : T)                                                                                  :
             : M]                                                                                  :
   25        :        34.5          19.8          14.0          16.3          24.7          61.8     :
             : T)                                                                                  :
             : M]                                                                                  :
   33        :        44.6          24.6          16.2          17.8          26.3          66.1     :
             : T)                                                                     67.7( 36.4)  :
             : M]                                                                                  :
   42        :        54.9          29.8          18.8          19.2          27.7          70.5     :
             : T)                                                                                  :
             : M]                                                                                  :
   54        :        67.8          36.7          21.9          21.0          29.5          76.5     :
             : T)   68.5( 55.1)                                                                    :
             : M]                                                                                  :
   70        :        81.1          45.1          25.8          23.1          31.7                   :
             : T)                 47.5( 75.6)                               32.5( 77.2)              :
             : M]                                                                                  :
   90        :                      53.7          30.6          25.7          34.0                   :
             : T)                               32.5( 99.3)   27.0(101.0)                          :
             : M]                                                                                  :
  115        :                                    35.8          28.6          37.1                   :
             : T)                                                                                  :
             : M]                                                                                  :
  148        :                                    40.4          31.9                                 :
             : T)                                                                                  :
             : M]                                                                                  :
             ---------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE   85.6( 79.9)   59.2(111.0)   40.7(151.0)   33.8(165.0)   40.7(131.0)   85.0( 62.3)
```

TABLE 39

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                        DENSIMETRIC FROUDE NUMBER

                       1             3             10            30            100           1000
RISE(DIA)    --------------------------------------------------------------------------------------
             : T)                                                                                  :
             : M]                              5.1[  0.9]   5.0[  0.1]   5.0[  0.0]   5.0[  0.0]   :
    1        :         1.9           2.7           5.3           8.2          12.9          31.8     :
             : T)                                                                                  :
             : M]                                                                                  :
    2        :         2.7           3.5           6.2           9.3          14.7          36.5     :
             : T)                                                                                  :
             : M]                                                                                  :
    3        :         3.6           4.3           6.9          10.1          16.0          39.6     :
             : T)                                                                                  :
             : M]                                                                                  :
    4        :         4.6           5.0           7.4          10.7          16.9          41.9     :
             : T)                                                                                  :
             : M]                                                                                  :
    5        :         5.7           5.8           7.8          11.2          17.6          44.0     :
             : T)                                                                                  :
             : M]                                                                                  :
    7        :         8.1           7.4           8.6          12.0          18.9          47.1     :
             : T)                                                                                  :
             : M]                                                                                  :
    9        :        10.9           9.1           9.3          12.6          19.8          49.5     :
             : T)                                                                                  :
             : M]                  9.4[  9.3]                                                      :
   12        :        15.6          11.4          10.3          13.5          21.1          52.4     :
             : T)                                                                                  :
             : M]   20.2[ 14.6]                                                                    :
   15        :        21.0          13.5          11.2          14.2          22.0          54.8     :
             : T)                                                                                  :
             : M]                                                                                  :
   20        :        28.2          16.7          12.6          15.3          23.4          58.0     :
             : T)                                                                                  :
             : M]                                                                                  :
   25        :        35.0          20.0          14.1          16.2          24.5          60.7     :
             : T)                                                                                  :
             : M]                                                                                  :
   33        :        45.5          24.9          16.3          17.6          26.0          64.4     :
             : T)                                                                                  :
             : M]                                                                                  :
   42        :        56.8          30.5          18.9          19.2          27.4          67.7     :
             : T)                                                                                  :
             : M]                                                                                  :
   54        :        71.9          37.8          22.2          21.0          29.1          71.2     :
             : T)                                                                                  :
             : M]                                                                                  :
   70        :        91.8          47.5          26.5          23.3          31.0          75.3     :
             : T)                                                                                  :
             : M]                                                                                  :
   90        :       115.0          59.2          32.0          25.9          33.0          79.7     :
             : T)                                                                                  :
             : M]                                                                                  :
  115        :       142.0          73.4          38.6          29.3          35.3          84.5     :
             : T) 151.0(124.0)                                                       88.3(137.0)   :
             : M]                                                                                  :
  148        :       172.0          91.2          47.1          33.5          37.9          90.1     :
             : T)              105.0(176.0)                                                        :
             : M]                                                                                  :
  190        :                     111.0          57.5          38.7          41.1          97.1     :
             : T)                                                                                  :
             : M]                                                                                  :
  244        :                     129.0          69.6          45.1          44.8                   :
             : T)                            70.3(248.0)  51.1(300.0)  46.8(276.0)                 :
             : M]                                                                                  :
             --------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 189.0(179.0) 131.0(257.0)  80.3(300.0)  51.2(301.0)  48.3(300.0) 107.0(234.0)
```

TABLE 40

DIFFUSER PLUME DILUTION
PORT SPACING = 5 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.00

```
                                  DENSIMETRIC FROUDE NUMBER

                     1             3             10            30            100           1000
RISE(DIA)  ------------------------------------------------------------------------------------------
           : M]                              5.1[  0.9]    5.0[  0.1]    5.0[  0.0]    5.0[  0.0]   :
    1      :         1.9           2.7           5.3           8.2          12.9          31.8      :
           : M]                                                                                      :
    2      :         2.7           3.5           6.2           9.3          14.7          36.5      :
           : M]                                                                                      :
    3      :         3.6           4.3           6.9          10.1          16.0          39.6      :
           : M]                                                                                      :
    4      :         4.6           5.0           7.4          10.7          16.9          41.9      :
           : M]                                                                                      :
    5      :         5.7           5.8           7.8          11.2          17.6          44.0      :
           : M]                                                                                      :
    7      :         8.1           7.4           8.6          12.0          18.9          46.8      :
           : M]                                                                                      :
    9      :        10.9           9.1           9.3          12.6          19.8          49.5      :
           : M]                  9.4[  9.3]                                                          :
   12      :        15.7          11.4          10.3          13.5          21.0          52.4      :
           : M]  20.4[ 14.7]                                                                         :
   15      :        21.0          13.5          11.2          14.2          22.0          54.8      :
           : M]                                                                                      :
   20      :        28.2          16.8          12.6          15.3          23.4          57.7      :
           : M]                                                                                      :
   25      :        35.0          20.0          14.1          16.2          24.5          60.4      :
           : M]                                                                                      :
   33      :        45.9          24.9          16.3          17.6          26.0          63.9      :
           : M]                                                                                      :
   42      :        57.6          30.7          18.9          19.2          27.4          67.1      :
           : M]                                                                                      :
   54      :        72.9          38.0          22.3          21.0          29.0          70.5      :
           : M]                                                                                      :
   70      :        93.6          48.1          26.7          23.3          30.8          74.3      :
           : M]                                                                                      :
   90      :       120.0          60.5          32.2          26.0          32.8          78.1      :
           : M]                                                                                      :
  115      :       152.0          75.7          39.4          29.5          35.1          82.1      :
           : M]                                                                                      :
  148      :       194.0          96.1          48.5          34.0          37.7          86.3      :
           : M]                                                                                      :
  190      :       248.0         122.0          60.0          39.6          40.9          90.9      :
           : M]                                                                                      :
  244      :       318.0         156.0          75.1          46.8          44.6          95.6      :
           : M]                                                                                      :
           ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 318.0(245.0) 190.0(301.0)  90.6(301.0)  54.2(301.0)  48.3(300.0)  99.8(300.0)
```

TABLE 41

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.10

```
                                         DENSIMETRIC FROUDE NUMBER

                         1             3            10            30            100          1000
RISE(DIA)   ----------------------------------------------------------------------------------------------
            : T)                                                                                         :
            : M]                                           15.9[  0.9]   15.9[  0.1]   15.9[  0.0]       :
    1       :           1.9           2.8           6.4       16.4          34.3          134.0          :
            : T)                                                                         163.0(  1.7)    :
            : M]                                                                                         :
    2       :           2.7           3.7           8.8       21.4          42.8          177.0          :
            : T)                                                                                         :
            : M]                                                                                         :
    3       :           3.5           4.6          11.1       25.3          49.1                         :
            : T)                                                                                         :
            : M]                                                                                         :
    4       :           4.5           5.6          13.5       28.8          54.5                         :
            : T)                                                           58.4(  4.8)                   :
            : M]                                                                                         :
    5       :           5.6           6.6          16.1       32.0          60.1                         :
            : T)                                                                                         :
            : M]                                 16.6[  5.2]                                             :
    7       :           8.1           8.8          21.3       38.6          72.0                         :
            : T)                                             39.9(  7.5)                                 :
            : M]                                                                                         :
    9       :          10.8          11.3          26.3       44.9                                       :
            : T)                                 32.4( 11.3)                                             :
            : M]                                                                                         :
   12       :          15.4          15.8          34.8                                                  :
            : T)                                                                                         :
            : M]                                                                                         :
   15       :          20.5          21.4          44.6                                                  :
            : T)   25.5( 17.6)   26.0( 17.1)                                                             :
            : M]                 24.1[ 16.2]                                                             :
   20       :          30.7          34.1                                                                :
            : T)                                                                                         :
            : M]   35.0[ 21.7]                                                                           :
            ----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  64.5( 23.5)  54.7( 22.6)  49.7( 16.1)  56.2( 11.6)  80.2(  7.6) 227.0(  2.7)
```

TABLE 42

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.10

```
                                  DENSIMETRIC FROUDE NUMBER

                      1           3          10          30         100       1000
RISE(DIA)  ----------------------------------------------------------------------------------
           : T)                                                                             :
           : M]                                         15.9[  0.9] 15.9[  0.1] 15.9[  0.0] :
    1      :         1.9         2.8         6.4        16.3        34.3       132.0        :
           : T)                                                                             :
           : M]                                                                             :
    2      :         2.7         3.7         8.8        21.4        42.2       168.0        :
           : T)                                                                             :
           : M]                                                                             :
    3      :         3.6         4.6        11.0        25.1        48.1       195.0        :
           : T)                                                               205.0(  3.4)  :
           : M]                                                                             :
    4      :         4.5         5.6        13.4        28.4        53.4       221.0        :
           : T)                                                                             :
           : M]                                                                             :
    5      :         5.6         6.6        16.0        31.8        58.0       254.0        :
           : T)                                                                             :
           : M]                             16.7[  5.3]                                     :
    7      :         8.1         8.8        21.0        37.8        66.7                    :
           : T)                                                                             :
           : M]                                                                             :
    9      :        10.9        11.2        25.8        43.7        75.0                    :
           : T)                                                     76.0(  9.4)             :
           : M]                                                                             :
   12      :        15.6        15.6        32.9        52.7        87.3                    :
           : T)                                         57.6( 13.8)                         :
           : M]                                                                             :
   15      :        21.0        20.7        40.5        61.4                                :
           : T)                             50.2( 18.7)                                     :
           : M]                 26.9[ 18.1]                                                 :
   20      :        31.1        30.9        54.2        77.7                                :
           : T)                                                                             :
           : M]                                                                             :
   25      :        43.1        41.3        70.9                                            :
           : T)     45.6( 26.0) 43.4( 26.1)                                                 :
           : M]     48.2[ 27.0]                                                             :
   33      :        65.3        70.5                                                        :
           : T)                                                                             :
           : M]                                                                             :
           ----------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 114.0( 34.4)  92.0( 34.4)  78.2( 26.5)  81.9( 20.8) 106.0( 14.8) 285.0(  5.4)
```

TABLE 43

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                   DENSIMETRIC FROUDE NUMBER

                   1            3            10            30            100           1000
RISE(DIA)   -----------------------------------------------------------------------------------------
            : T)                                                                                    :
            : M]                                     15.9[  0.9]  15.9[  0.1]  15.9[  0.0]          :
    1       :      1.9          2.8          6.4         16.3          34.3         131.0           :
            : T)                                                                                    :
            : M]                                                                                    :
    2       :      2.7          3.7          8.8         21.3          42.2         164.0           :
            : T)                                                                                    :
            : M]                                                                                    :
    3       :      3.6          4.6         11.0         25.1          47.8         189.0           :
            : T)                                                                                    :
            : M]                                                                                    :
    4       :      4.5          5.6         13.4         28.4          53.0         208.0           :
            : T)                                                                                    :
            : M]                                                                                    :
    5       :      5.6          6.6         15.9         31.5          57.2         224.0           :
            : T)                                                                                    :
            : M]                       16.8[  5.4]                                                  :
    7       :      8.1          8.7         20.8         37.5          65.3         254.0           :
            : T)                                                                                    :
            : M]                                                                                    :
    9       :     10.9         11.2         25.4         43.4          72.9         283.0           :
            : T)                                                              289.0(  9.5)          :
            : M]                                                                                    :
   12       :     15.7         15.5         32.2         51.6          83.2         324.0           :
            : T)                                                                                    :
            : M]                                                                                    :
   15       :     21.1         20.4         39.1         60.1          93.6         381.0           :
            : T)                                                                                    :
            : M]          28.6[ 19.2]                                                               :
   20       :     31.5         30.3         50.2         73.5         110.0                         :
            : T)                                                124.0( 24.5)                        :
            : M]                                                                                    :
   25       :     44.0         39.9         61.8         87.4         126.0                         :
            : T)                                     107.0( 32.1)                                   :
            : M]  59.7[ 30.7]                                                                       :
   33       :     66.2         54.9         81.5        109.0         152.0                         :
            : T)                         99.7( 39.8)                                                :
            : M]                                                                                    :
   42       :     88.0         72.5        107.0        136.0                                       :
            : T)  97.9( 46.4)  87.4( 49.4)                                                          :
            : M]                                                                                    :
   54       :    115.0         99.0        150.0                                                    :
            : T)                                                                                    :
            : M]                                                                                    :
            -----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 241.0( 62.5) 192.0( 66.0) 156.0( 55.2) 153.0( 47.3) 174.0( 37.7) 404.0( 15.3)
```

TABLE 44

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                      DENSIMETRIC FROUDE NUMBER

                     1            3            10           30            100          1000
RISE(DIA)   -------------------------------------------------------------------------------------
            : T)                                                                                  :
            : M]                                       15.9[  0.9]  15.9[  0.1]  15.9[  0.0]    :
    1       :       1.9          2.8          6.4         16.3          34.0         131.0       :
            : T)                                                                                  :
            : M]                                                                                  :
    2       :       2.7          3.7          8.8         21.3          42.2         163.0       :
            : T)                                                                                  :
            : M]                                                                                  :
    3       :       3.6          4.6         11.0         25.1          47.8         186.0       :
            : T)                                                                                  :
            : M]                                                                                  :
    4       :       4.5          5.6         13.4         28.4          52.7         205.0       :
            : T)                                                                                  :
            : M]                                                                                  :
    5       :       5.6          6.6         15.9         31.5          57.2         221.0       :
            : T)                                                                                  :
            : M]                          16.8[  5.4]                                             :
    7       :       8.1          8.7         20.8         37.5          65.3         248.0       :
            : T)                                                                                  :
            : M]                                                                                  :
    9       :      10.9         11.2         25.4         43.1          72.4         271.0       :
            : T)                                                                                  :
            : M]                                                                                  :
   12       :      15.7         15.5         32.2         51.6          82.6         299.0       :
            : T)                                                                                  :
            : M]                                                                                  :
   15       :      21.1         20.4         38.6         59.7          92.3         325.0       :
            : T)                                                                                  :
            : M]               29.0[ 19.5]                                                        :
   20       :      31.8         30.3         49.5         72.9         108.0         363.0       :
            : T)                                                                                  :
            : M]                                                                                  :
   25       :      44.0         39.9         60.1         86.1         124.0         398.0       :
            : T)                                                                    439.0( 31.5)  :
            : M]  63.5[ 31.8]                                                                     :
   33       :      67.1         54.5         77.6        108.0         146.0         449.0       :
            : T)                                                                                  :
            : M]                                                                                  :
   42       :      91.1         71.0         97.6        131.0         173.0                     :
            : T)                                                                                  :
            : M]                                                                                  :
   54       :     121.0         93.0        124.0        163.0         207.0                     :
            : T)                                                    245.0( 67.7)                 :
            : M]                                                                                  :
   70       :     158.0        122.0        167.0        204.0         252.0                     :
            : T)                                       231.0( 79.7)                               :
            : M]                                                                                  :
   90       :     204.0        159.0        216.0        259.0         309.0                     :
            : T) 216.0( 95.7) 194.0(107.0) 221.0( 91.7)                                          :
            : M]                                                                                  :
  115       :     260.0        213.0        299.0                                               :
            : T)                                                                                  :
            : M]                                                                                  :
             -------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 310.0(128.0) 387.0(142.0) 331.0(123.0) 313.0(109.0) 320.0( 93.8) 456.0( 34.1)
```

TABLE 45

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.10

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	: M]				15.9[0.9]	15.9[0.1]	15.9[0.0]
1	:	1.9	2.8	6.4	16.3	34.0	131.0
	: M]						
2	:	2.7	3.7	8.8	21.3	42.2	163.0
	: M]						
3	:	3.6	4.6	11.0	25.1	47.8	186.0
	: M]						
4	:	4.5	5.6	13.4	28.4	52.7	205.0
	: M]						
5	:	5.6	6.6	15.9	31.5	57.2	220.0
	: M]			16.8[5.4)			
7	:	8.1	8.7	20.8	37.5	64.8	246.0
	: M]						
9	:	10.9	11.7	25.4	43.1	72.4	268.0
	: M]						
12	:	15.7	15.3	32.0	51.6	82.6	296.0
	: M]						
15	:	21.1	20.4	38.6	59.7	92.3	320.0
	: M]		29.2[19.6)				
20	:	31.8	30.3	49.1	72.9	108.0	354.0
	: M]						
25	:	44.3	39.9	60.1	86.1	123.0	383.0
	: M]	64.8[32.2)					
33	:	67.6	54.5	76.6	107.0	146.0	425.0
	: M]						
42	:	91.7	71.0	95.6	130.0	171.0	
	: M]						
53	:	123.0	92.3	121.0	161.0	205.0	
	: M]						
70	:	162.0	121.0	154.0	202.0	249.0	
	: M]						
90	:	212.0	156.0	196.0	252.0	303.0	
	: M]						
115	:	273.0	201.0	247.0	315.0	369.0	
	: M]						
148	:	354.0	259.0	316.0	398.0		
	: M]						
190	:		333.0				
	: M]						
DIL AT MAX REAL OR PERMITTED RISE		397.0(166.0)	356.0(203.0)	376.0(177.0)	400.0(149.0)	400.0(127.0)	464.0(41.7)

TABLE .46

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.05

```
                                        DENSIMETRIC FROUDE NUMBER

                    1            3           10           30          100         1000
RISE(DIA)       --------------------------------------------------------------------------------
           : T)                                                                                :
           : M]                                        12.6[  0.8]  12.6[  0.1]  12.6[  0.0]   :
   1       :       1.9          2.8          5.9         13.6         26.2         94.9        :
           : T)                                                                                :
           : M]                                                                                :
   2       :       2.7          3.6          7.6         16.9         32.0        121.0        :
           : T)                                                                 124.0(  2.2)   :
           : M]                                                                                :
   3       :       3.6          4.4          9.1         19.2         36.0        145.0        :
           : T)                                                                                :
           : M]                                                                                :
   4       :       4.6          5.1         10.3         21.1         39.6                     :
           : T)                                                                                :
           : M]                                                                                :
   5       :       5.6          6.0         11.7         22.8         42.8                     :
           : T)                                                     45.5(  5.9)                :
           : M]                           14.0[  6.8]                                          :
   7       :       8.1          7.6         14.3         26.2         49.1                     :
           : T)                                                                                :
           : M]                                                                                :
   9       :      10.8          9.4         16.8         29.2         56.5                     :
           : T)                                        29.8(  9.4)                             :
           : M]                                                                                :
  12       :      15.4         12.3         20.3         34.3                                  :
           : T)                           22.9( 14.3)                                          :
           : M]                                                                                :
  15       :      20.3         15.5         23.9                                               :
           : T)   24.9( 17.7)  20.5( 19.2)                                                     :
           : M]                                                                                :
  20       :      29.3         21.7         32.7                                               :
           : T)                                                                                :
           : M]   33.4[ 22.4]  22.6[ 20.7]                                                     :
  25       :                   28.9                                                            :
           : T)                                                                                :
           : M]                                                                                :
                --------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  54.2( 24.0)  41.6( 26.6)  36.6( 21.1)  41.6( 14.9)  62.0(  9.6) 172.0(  3.5)
```

TABLE 47

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.05

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.8	5.9	12.6[0.8] 13.5	12.6[0.1] 26.2	12.6[0.0] 94.3
2	2.7	3.6	7.6	16.9	31.8	117.0
3	3.6	4.4	9.0	19.0	35.7	134.0
4	4.6	5.1	10.3	21.0	38.8	150.0 155.0(4.4)
5	5.7	6.0	11.6	22.6	41.9	164.0
7	8.1	7.6	14.2[7.1]	25.6	46.8	205.0
9	10.9	9.4	16.6	28.6	51.6 57.6(11.9)	
12	15.5	12.3	19.7	32.9	58.0	
15	20.8	15.6	22.9	37.0 41.3(18.1)	64.8	
20	30.7	21.6	28.0 33.8(25.2)	44.3		
25	41.3 44.0(26.2)	27.1[24.0] 28.4 34.5(30.1)		52.6		
33	47.5[27.8] 56.5	38.0	46.2			
DIL AT MAX REAL OR PERMITTED RISE	98.4(35.3)	72.4(41.4)	58.7(36.4)	59.5(27.9)	79.3(19.1)	215.0(7.1)

TABLE 48

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                 DENSIMETRIC FROUDE NUMBER

                    1           3           10          30          100         1000
RISE(DIA)  ------------------------------------------------------------------------------
           : T)                                                                         :
           : M]                                     12.7[  0.8] 12.6[  0.1] 12.6[  0.0] :
    1      :       1.9         2.8         5.9        13.5        26.2        93.6      :
           : T)                                                                         :
           : M]                                                                         :
    2      :       2.7         3.6         7.6        16.8        31.5       115.0      :
           : T)                                                                         :
           : M]                                                                         :
    3      :       3.6         4.4         9.0        19.0        35.5       131.0      :
           : T)                                                                         :
           : M]                                                                         :
    4      :       4.6         5.1        10.3        20.8        38.6       144.0      :
           : T)                                                                         :
           : M]                                                                         :
    5      :       5.7         6.0        11.6        22.5        41.3       155.0      :
           : T)                                                                         :
           : M]                                                                         :
    7      :       8.1         7.6        14.1        25.4        46.2       174.0      :
           : T)                                                                         :
           : M]                         14.3[  7.2]                                     :
    9      :      10.9         9.4        16.4        28.2        50.2       191.0      :
           : T)                                                                         :
           : M]                                                                         :
   12      :      15.6        12.3        19.6        32.2        56.1       214.0      :
           : T)                                                             217.0( 17.6):
           : M]                                                                         :
   15      :      21.0        15.6        22.5        36.0        61.8       236.0      :
           : T)                                                                         :
           : M]                                                                         :
   20      :      31.3        21.7        27.3        42.2        70.0       287.0      :
           : T)                                                                         :
           : M]                                                                         :
   25      :      43.1        28.6        32.0        48.5        78.7                  :
           : T)                                                 90.6( 32.4)             :
           : M]  60.1[ 31.6] 30.1[ 26.0]                                                :
   33      :      64.0        39.4        39.6        58.4        92.0                  :
           : T)                                                                         :
           : M]                                                                         :
   42      :      82.7        50.2        48.5        70.5       107.0                  :
           : T)  92.4( 47.3)                      73.9( 44.7)                           :
           : M]                                                                         :
   54      :     104.0        64.0        60.9        88.3                              :
           : T)              68.7( 58.5) 64.0( 56.7)                                    :
           : M]                                                                         :
   70      :                  81.8        84.0                                          :
           : T)                                                                         :
           : M]                                                                         :
           ------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 213.0( 65.2) 157.0( 81.4) 123.0( 79.9) 111.0( 66.0) 127.0( 50.6) 302.0( 20.3)
```

TABLE 49

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                     DENSIMETRIC FROUDE NUMBER
                       1            3            10           30           100          1000
                                                                         ----------------------
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)                                                                               :
           : M)                                        12.7[  0.8]  12.6[  0.1]  12.6[  0.0]  :
    1      :          1.9          2.8          5.9      13.5         26.2         93.6        :
           : T)                                                                               :
           : M)                                                                               :
    2      :          2.7          3.6          7.6      16.8         31.5        115.0        :
           : T)                                                                               :
           : M)                                                                               :
    3      :          3.6          4.4          9.0      19.0         35.5        131.0        :
           : T)                                                                               :
           : M)                                                                               :
    4      :          4.6          5.1         10.3      20.8         38.6        143.0        :
           : T)                                                                               :
           : M)                                                                               :
    5      :          5.7          6.0         11.6      22.5         41.3        153.0        :
           : T)                                                                               :
           : M)                                                                               :
    7      :          8.1          7.6         14.0      25.4         45.9        171.0        :
           : T)                                                                               :
           : M)                           14.3[  7.2]                                         :
    9      :         10.9          9.4         16.3      28.2         50.2        185.0        :
           : T)                                                                               :
           : M)                                                                               :
   12      :         15.7         12.3         19.6      32.0         55.7        204.0        :
           : T)                                                                               :
           : M)                                                                               :
   15      :         21.0         15.6         22.5      35.7         60.9        220.0        :
           : T)                                                                               :
           : M)                                                                               :
   20      :         31.3         21.7         27.3      41.9         69.5        244.0        :
           : T)                                                                               :
           : M)                                                                               :
   25      :         43.4         28.8         31.8      47.8         77.1        265.0        :
           : T)                                                                               :
           : M)  63.9[ 32.6]  30.9[ 26.5]                                                     :
   33      :         65.3         39.6         39.1      56.8         89.1        295.0        :
                                                                              326.0( 41.8)  :
           : T)                                                                               :
           : M)                                                                               :
   42      :         87.4         50.9         47.5      67.6        103.0        326.0        :
           : T)                                                                               :
           : M)                                                                               :
   54      :        114.0         65.3         58.0      81.5        120.0                     :
           : T)                                                                               :
           : M)                                                                               :
   70      :        147.0         84.3         72.9     100.0        143.0                     :
           : T)                                                                               :
           : M)                                                                               :
   90      :        185.0        107.0         91.0     125.0        172.0                     :
           : T)  201.0( 99.1)                         158.0(115.0) 175.0( 92.6)                :
           : M)                                                                               :
  115      :        227.0        135.0        116.0                  208.0                     :
                             151.0(129.0) 140.0(138.0)                                        :
           : T)                                                                               :
           : M)                                                                               :
  144      :                     172.0        153.0     211.0                                  :
           : T)                                                                               :
           : M)                                                                               :
           ------------------------------------------------------------------------------------

DIL AT MAX PEAK
OR PERMITTED RISE 259.0(136.0) 294.0(180.0) 284.0(189.0) 240.0(163.0) 239.0(135.0) 361.0( 51.8)
```

TABLE 50

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.05

```
                                  DENSIMETRIC FROUDE NUMBER

                      1             3             10            30            100           1000
RISE(DIA)  ----------------------------------------------------------------------------------------------
           : M]                                           12.7[  0.8]  12.6[  0.1]  12.6[  0.0]  :
   1       :         1.9           2.8           5.9       13.5          26.2          93.6        :
           : M]                                                                                 :
   2       :         2.7           3.6           7.6       16.8          31.5         115.0        :
           : M]                                                                                 :
   3       :         3.6           4.4           9.0       19.0          35.5         131.0        :
           : M]                                                                                 :
   4       :         4.6           5.1          10.3       20.8          38.6         143.0        :
           : M]                                                                                 :
   5       :         5.7           6.0          11.6       22.5          41.3         153.0        :
           : M]                                                                                 :
   7       :         8.1           7.6          14.0       25.4          45.9         170.0        :
           : M]                              14.3[  7.3]                                        :
   9       :        10.9           9.4          16.3       28.2          50.2         184.0        :
           : M]                                                                                 :
  12       :        15.7          12.3          19.6       32.0          55.7         202.0        :
           : M]                                                                                 :
  15       :        21.1          15.6          22.5       35.7          60.9         218.0        :
           : M]                                                                                 :
  20       :        31.5          21.7          27.1       41.9          69.0         240.0        :
           : M]                                                                                 :
  25       :        43.4          28.8          31.8       47.5          77.1         259.0        :
           : M]  64.8[ 32.8]  31.1[ 26.6]                                                       :
  33       :        65.7          39.9          39.1       56.8          89.2         284.0        :
           : M]                                                                                 :
  42       :        88.0          51.2          47.1       66.7         102.0         310.0        :
           : M]                                                                                 :
  54       :       116.0          65.7          57.6       79.8         119.0         339.0        :
           : M]                                                                                 :
  70       :       152.0          85.6          71.9       97.2         141.0                      :
           : M]                                                                                 :
  90       :       196.0         109.0          89.4      119.0         168.0                      :
           : M]                                                                                 :
 115       :       251.0         140.0         111.0      146.0         201.0                      :
           : M]                                                                                 :
 148       :       324.0         179.0         141.0      181.0         245.0                      :
           : M]                                                                                 :
 190       :                     229.0         177.0      226.0         300.0                      :
           : M]                                                                                 :
 244       :                     294.0         224.0      283.0                                    :
           : M]                                                                                 :
           ----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 382.0(174.0) 310.0(258.0) 273.0(300.0) 295.0(256.0) 312.0(200.0) 370.0( 67.5)
```

TABLE 51

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.02

```
                                   DENSIMETRIC FROUDE NUMBER

                      1            3            10            30           100          1000
RISE(DIA)  ----------------------------------------------------------------------------------------
           : T)                                                                                   :
           : M)                                     11.1[  0.8]  11.0(  0.1)  11.0[  0.0)         :
    1      :         1.9          2.7          5.5      11.7         20.8         64.8            :
           : T)                                                                                   :
           : M)                                                                                   :
    2      :         2.7          3.6          7.1      14.1         24.6         79.8            :
           : T)                                                                 90.4(  2.9)       :
           : M)                                                                                   :
    3      :         3.6          4.3          8.2      15.7         27.1         91.7            :
           : T)                                                                                   :
           : M)                                                                                   :
    4      :         4.6          5.1          9.3      16.9         29.4        104.0            :
           : T)                                                                                   :
           : M)                                                                                   :
    5      :         5.7          5.9         10.2      17.9         31.3                         :
           : T)                                                                                   :
           : M)                                                                                   :
    7      :         8.1          7.5         12.0      19.7         34.8                         :
           : T)                                                   35.2(  7.4)                     :
           : M)                          12.8[  8.0]                                              :
    9      :        10.8          9.2         13.6      21.3         38.0                         :
           : T)                                       22.9( 11.4)                                 :
           : M)                                                                                   :
   12      :        15.2         12.0         15.6      23.4         44.7                         :
           : T)                                                                                   :
           : M)                                                                                   :
   15      :        20.3         14.9         17.4      25.8                                      :
           : T)  24.8( 17.6)  19.7( 19.6)  18.3( 16.5)                                            :
           : M)                                                                                   :
   20      :        29.0         20.1         20.4                                                :
           : T)                                                                                   :
           : M)  32.9[ 22.4]  22.0[ 21.8]                                                         :
   25      :                      24.9         24.9                                               :
           : T)                                                                                   :
           : M)                                                                                   :
            ---------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  44.1( 24.0)  32.0( 27.7)  26.1( 25.4)  30.7( 18.8)  46.7( 12.2) 123.0(  4.8)
```

TABLE 52

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.02

```
                                  DENSIMETRIC FROUDE NUMBER

                   1             3             10            30            100           1000
RISE(DIA)  ------------------------------------------------------------------------------------------
           : T)                                                                                    :
           : M]                                          11.1[  0.8]   11.0[  0.1]   11.0[  0.0]   :
    1      :       1.9           2.7           5.5           11.7          20.8          64.4        :
           : T)                                                                                    :
           : M]                                                                                    :
    2      :       2.7           3.6           7.1           14.1          24.4          78.2        :
           : T)                                                                                    :
           : M]                                                                                    :
    3      :       3.6           4.3           8.2           15.7          26.9          88.6        :
           : T)                                                                                    :
           : M]                                                                                    :
    4      :       4.6           5.1           9.3           16.8          29.0          96.9        :
           : T)                                                                                    :
           : M]                                                                                    :
    5      :       5.7           5.9           10.2          17.7          30.7          105.0       :
           : T)                                                                      111.0(  6.0)  :
           : M]                                                                                    :
    7      :       8.1           7.5           11.9          19.4          33.8          118.0       :
           : T)                                                                                    :
           : M]                            13.2[  8.6]                                             :
    9      :       10.9          9.2           13.5          20.8          36.2          135.0       :
           : T)                                                                                    :
           : M]                                                                                    :
   12      :       15.5          12.0          15.6          22.8          39.6                      :
           : T)                                                                                    :
           : M]                                                                                    :
   15      :       20.7          15.1          17.4          24.4          42.8                      :
           : T)                                                        43.1( 15.4)                 :
           : M]                                                                                    :
   20      :       30.5          20.7          20.1          27.3          48.0                      :
           : T)                                          29.0( 23.3)                               :
           : M]              26.9[ 25.2]                                                           :
   25      :       41.3                        22.8          30.1          56.2                      :
           : T)  43.7( 26.2)   32.7( 30.9)   25.5( 30.1)                                             :
           : M]  47.5[ 27.9]                                                                       :
   33      :       55.2          34.5          27.1          35.4                                    :
           : T)                                                                                    :
           : M]                                                                                    :
   42      :                     41.5          32.4                                                  :
           : T)                                                                                    :
           : M]                                                                                    :
           ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  81.4( 35.6)  54.6( 43.6)  40.0( 46.1)  40.7( 37.5)  57.7( 25.1) 152.0(  9.8)
```

TABLE 53

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.02

```
                                    DENSIMETRIC FROUDE NUMBER

                     1              3              10             30             100            1000
RISE(DIA)  ---------------------------------------------------------------------------------------------------
           : T)                                                                                              :
           : M]                                                                                              :
    1      :         1.9            2.7            5.5        11.1[  0.8]   11.0[  0.1]   11.0[  0.0]        :
           : T)                                                  11.7          20.7          63.9            :
           : M]                                                                                              :
    2      :         2.7            3.6            7.1            14.1          24.4          77.6           :
           : T)                                                                                              :
           : M]                                                                                              :
    3      :         3.6            4.3            8.2            15.6          26.9          87.3           :
           : T)                                                                                              :
           : M]                                                                                              :
    4      :         4.6            5.1            9.3            16.8          28.8          94.9           :
           : T)                                                                                              :
           : M]                                                                                              :
    5      :         5.7            5.9           10.1            17.7          30.5         101.0           :
           : T)                                                                                              :
           : M]                                                                                              :
    7      :         8.1            7.5           11.9            19.3          33.3         112.0           :
           : T)                                                                                              :
           : M]                                  13.4[  8.9]                                                 :
    9      :        10.9            9.2           13.5            20.7          35.7         121.0           :
           : T)                                                                                              :
           : M]                                                                                              :
   12      :        15.6           12.0           15.5            22.5          38.6         134.0           :
           : T)                                                                                              :
           : M]                                                                                              :
   15      :        21.0           15.1           17.3            24.1          41.3         144.0           :
           : T)                                                                             152.0( 17.4)     :
           : M]                                                                                              :
   20      :        31.1           21.0           20.2            26.5          45.2         162.0           :
           : T)                                                                                              :
           : M]                                                                                              :
   25      :        42.8           27.5           22.9            28.8          48.7         181.0           :
           : T)                                                                                              :
           : M]   59.7[ 31.5]    29.8[ 26.9]                                                                 :
   33      :        63.5           37.0           27.3            32.4          53.9                         :
           : T)                                                                                              :
           : M]                                                                                              :
   42      :        82.1           46.2           31.8            36.5          60.1                         :
           : T)   90.8( 47.3)                                                 61.5( 44.4)                    :
           : M]                                                                                              :
   54      :       101.0           57.6           37.8            41.8          68.1                         :
           : T)                  63.4( 61.1)                   46.5( 64.1)                                   :
           : M]                                                                                              :
   70      :                       70.4           45.6            49.7          81.7                         :
           : T)                                 46.4( 71.7)                                                  :
           : M]                                                                                              :
   90      :                                      55.5            62.6                                       :
           : T)                                                                                              :
           : M]                                                                                              :
           ---------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 184.0( 66.0) 122.0( 87.2)  85.1(106.0)  71.5( 97.9)  85.3( 71.5) 209.0( 28.6)
```

TABLE 54

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.7	5.5	11.1[0.8] 11.7	11.0[0.1] 20.7	11.0[0.0] 63.9
2	2.7	3.6	7.1	14.1	24.4	77.6
3	3.6	4.3	8.2	15.6	26.9	86.7
4	4.6	5.1	9.3	16.8	28.8	94.3
5	5.7	5.9	10.1	17.7	30.5	100.0
7	8.1	7.5	11.9	19.3	33.3	111.0
9	10.9	9.2	13.4[8.9] 13.5	20.7	35.5	119.0
12	15.6	12.0	15.5	22.3	38.3	130.0
15	21.0	15.2	17.3	23.9	41.0	139.0
20	31.3	21.0	20.2	26.3	44.6	153.0
25	43.4	27.5	22.9	28.6	47.8	164.0
33	63.5[32.5] 65.3	30.9[27.5] 37.8	27.3	32.2	53.0	180.0
42	86.1	47.5	32.0	36.0	57.9	196.0
54	112.0	60.5	38.3	40.8	64.6	216.0 224.0(59.7)
70	143.0	76.6	46.5	47.0	73.0	241.0
90	179.0 196.0(100.0)	96.1	56.7	54.7	83.5	
115	219.0	119.0 137.0(136.0)	69.2	64.7	96.7 109.0(139.0)	
148		147.0	65.3 99.4(179.0)	77.6 91.9(182.0)	115.0	
190		176.0	105.0	95.9	142.0	
244			135.0	133.0		
DIL AT MAX REAL OR PERMITTED RISE	245.0(138.0)	200.0(197.0)	214.0(259.0)	172.0(264.0)	160.0(212.0)	264.0(83.7)

TABLE 55

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	M]				11.1[0.8]	11.0[0.1]	11.0[0.0]
1		1.9	2.7	5.5	11.7	20.7	63.9
	M]						
2		2.7	3.6	7.1	14.1	24.4	77.6
	M]						
3		3.6	4.3	8.7	15.6	26.9	86.7
	M]						
4		4.6	5.1	9.3	16.7	28.8	94.3
	M]						
5		5.7	5.9	10.1	17.7	30.5	100.0
	M]						
7		8.1	7.5	11.9	19.3	33.1	111.0
	M]			13.5[9.1]			
9		10.9	9.2		20.5	35.5	119.0
	M]						
12		15.7	12.0	15.5	22.3	38.3	130.0
	M]						
15		21.0	15.2	17.3	23.9	40.8	138.0
	M]						
20		31.3	21.1	20.2	26.3	44.6	151.0
	M]						
25		43.4	27.7	22.9	28.6	47.8	162.0
	M]	64.8[32.8]	31.1[27.6]				
33		65.7	37.8	27.3	32.0	52.8	176.0
	M]						
42		87.3	47.8	32.2	35.7	57.7	190.0
	M]						
54		114.0	60.9	38.6	40.5	64.0	206.0
	M]						
70		148.0	78.2	46.8	46.8	72.0	225.0
	M]						
90		191.0	99.0	57.2	54.2	81.5	245.0
	M]						
115		244.0	125.0	70.3	63.7	93.1	268.0
	M]						
148		314.0	160.0	87.6	75.7	108.0	
	M]						
190			204.0	110.0	91.2	126.0	
	M]						
244			260.0	137.0	111.0	149.0	
	M]						

DIL AT MAX REAL
OR PERMITTED RISE 375.0(178.0) 295.0(278.0) 166.0(301.0) 131.0(300.0) 173.0(300.0) 271.0(119.0)

TABLE 56

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                      1             3             10            30            100           1000
RISE(DIA)  -----------------------------------------------------------------------------------------
           : T)                                                                                    :
           : M]                                       10.1[  0.9]  10.1[  0.1]  10.1[  0.0]        :
    1      :         1.9           2.7           5.3     10.6          17.3          42.5          :
           : T)                                                                                    :
           : M]                                                                                    :
    2      :         2.7           3.5           6.7     12.5          19.8          49.1          :
           : T)                                                                                    :
           : M]                                                                                    :
    3      :         3.6           4.3           7.8     13.6          21.5          53.8          :
           : T)                                                                                    :
           : M]                                                                                    :
    4      :         4.6           5.0           8.7     14.4          22.8          57.6          :
           : T)                                                                  58.4(  4.3)       :
           : M]                                                                                    :
    5      :         5.7           5.8           9.6     15.2          23.9          60.9          :
           : T)                                                                                    :
           : M]                                                                                    :
    7      :         8.1           7.4          11.2     16.4          25.8          69.6          :
           : T)                                                    27.5(  9.2)                     :
           : M]                              12.1[  8.3]                                           :
    9      :        10.8           9.1          12.6     17.4                                      :
           : T)                                                                                    :
           : M]                                                                                    :
   12      :        15.2          11.8          14.3     18.8          29.8                        :
           : T)                                       19.3( 13.4)                                  :
           : M]                                                                                    :
   15      :        20.3          14.7          15.8     20.0          32.8                        :
           : T)  24.8( 17.7)  19.6( 19.8)  16.8( 17.5)                                             :
           : M]                                                                                    :
   20      :        28.8          19.8          17.9     22.1                                      :
           : T)                                                                                    :
           : M]  32.9[ 22.5]  21.9[ 22.0]                                                          :
   25      :                      24.1          19.6                                               :
           : T)                                                                                    :
           : M]                                                                                    :
           -----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  34.1( 24.1)  25.4( 28.1)  20.7( 27.6)  23.9( 22.2)  34.3( 15.4)  73.3(  7.3)
```

TABLE 57

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.00

```
                                     DENSIMETRIC FROUDE NUMBER

                      1            3            10           30           100          1000
                 ---------------------------------------------------------------------------------
RISE(DIA)  --------------------------------------------------------------------------------      :
           : T)                                                                                  :
           : M)                                      10.1(  0.9)  10.1(  0.1]  10.1[  0.0]      :
    1      :         1.9          2.7          5.3        10.6         17.3         42.2         :
           : T)                                                                                  :
           : M)                                                                                  :
    2      :         2.7          3.5          6.7        12.5         19.7         48.5         :
           : T)                                                                                  :
           : M)                                                                                  :
    3      :         3.6          4.3          7.7        13.5         21.4         53.0         :
           : T)                                                                                  :
           : M)                                                                                  :
    4      :         4.6          5.0          8.7        14.4         22.6         56.1         :
           : T)                                                                                  :
           : M)                                                                                  :
    5      :         5.7          5.8          9.5        15.1         23.7         58.8         :
           : T)                                                                                  :
           : M)                                                                                  :
    7      :         8.1          7.4         11.2        16.2         25.4         63.5         :
           : T)                                                                    67.8(  9.2)   :
           : M)                         12.5[  8.8]                                              :
    9      :        10.9          9.1         12.6        17.3         26.7                      :
           : T)                                                                                  :
           : M)                                                                                  :
   12      :        15.5         11.9         14.4        18.5         28.4         73.6         :
           : T)                                                                                  :
           : M)                                                                                  :
   15      :        20.7         14.9         16.0        19.6         30.0         81.0         :
           : T)                                                       31.9( 19.4)                :
           : M)                                                                                  :
   20      :        30.5         20.5         18.3        21.1         32.2                      :
           : T)                                                                                  :
           : M)                                                                                  :
   25      :        41.1         26.5         20.4        22.6         34.3                      :
           : T)  43.7( 26.2)  32.2( 31.2)  23.1( 32.1)  23.2( 27.6)                              :
           : M)  47.2[ 27.8)  26.7[ 25.3]                                                        :
   33      :        54.6         33.8         23.4        24.7         39.4                      :
           : T)                                                                                  :
           : M)                                                                                  :
   42      :                     38.9         26.3        27.0                                   :
           : T)                                                                                  :
           : M)                                                                                  :
           -----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  56.4( 35.6)  39.5( 44.2)  28.6( 50.7)  29.0( 46.3)  40.0( 33.1)  85.1( 15.6)
```

TABLE 58

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                 DENSIMETRIC FROUDE NUMBER

                     1            3            10           30           100          1000
RISE(DIA)  ----------------------------------------------------------------------------------
           : T)                                                                              :
           : M]                                            10.1[  0.9]  10.1[  0.1]  10.1[  0.0]  :
    1      :        1.9          2.7          5.3           10.6         17.3         42.2   :
           : T)                                                                              :
           : M]                                                                              :
    2      :        2.7          3.5          6.7           12.4         19.7         48.5   :
           : T)                                                                              :
           : M]                                                                              :
    3      :        3.6          4.3          7.7           13.5         21.4         52.7   :
           : T)                                                                              :
           : M]                                                                              :
    4      :        4.6          5.0          8.7           14.4         22.6         55.7   :
           : T)                                                                              :
           : M]                                                                              :
    5      :        5.7          5.8          9.5           15.0         23.6         58.4   :
           : T)                                                                              :
           : M]                                                                              :
    7      :        8.1          7.4         11.1           16.2         25.3         62.2   :
           : T)                                                                              :
           : M]                            12.6[  9.1]                                       :
    9      :       10.9          9.1                        17.1         26.5         65.5   :
           : T)                                                                              :
           : M]                                                                              :
   12      :       15.6         17.0         14.4           18.4         28.0         70.0   :
           : T)                                                                              :
           : M]                                                                              :
   15      :       21.0         15.0         16.1           19.4         29.4         73.3   :
           : T)                                                                              :
           : M]                                                                              :
   20      :       31.1         20.8         18.5           21.0         31.2         78.0   :
           : T)                                                                              :
           : M]                                                                              :
   25      :       42.9         27.1         20.8           22.3         32.9         82.3   :
           : T)                                                                85.2( 28.7)   :
           : M]  59.7[ 31.5]  29.8[ 27.1]                                                    :
   33      :       63.5         36.5         24.4           24.4         35.0         88.5   :
           : T)                                                                              :
           : M]                                                                              :
   42      :       81.5         45.2         28.2           26.5         37.1         95.7   :
           : T)  90.4( 47.6)                                                                 :
           : M]                                                                              :
   54      :       99.9         55.7         33.1           29.2         39.7                :
           : T)              61.4( 61.6)                             41.0( 60.9)              :
           : M]                                                                              :
   70      :                    67.4         39.2           32.5         42.7                :
           : T)                           41.6( 77.3)  34.2( 80.0)                           :
           : M]                                                                              :
   90      :                                 45.6           36.1         46.6                :
           : T)                                                                              :
           : M]                                                                              :
  115      :                                 51.3           40.1                             :
           : T)                                                                              :
           : M]                                                                              :
           ----------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 111.0( 66.4)  76.0( 89.3)  51.7(118.0)  42.8(130.0)  51.3(104.0) 107.0( 49.5)
```

TABLE 59

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                         DENSIMETRIC FROUDE NUMBER

                         1            3             10            30            100            1000
RISE(DIA)   -------------------------------------------------------------------------------------------------
            : T)                                                                                            :
            : M]                                          10.1[  0.9]   10.1[  0.1]   10.1[  0.0]           :
    1       :          1.9          2.7           5.3         10.6          17.3          42.2              :
            : T)                                                                                            :
            : M]                                                                                            :
    2       :          2.7          3.5           6.7         12.4          19.7          48.5              :
            : T)                                                                                            :
            : M]                                                                                            :
    3       :          3.6          4.3           7.7         13.5          21.3          52.3              :
            : T)                                                                                            :
            : M]                                                                                            :
    4       :          4.6          5.0           8.7         14.4          22.5          55.7              :
            : T)                                                                                            :
            : M]                                                                                            :
    5       :          5.7          5.8           9.5         15.0          23.6          58.0              :
            : T)                                                                                            :
            : M]                                                                                            :
    7       :          8.1          7.4          11.1         16.2          25.1          62.2              :
            : T)                                                                                            :
            : M]                                                                                            :
    9       :         10.9          9.1          12.6         17.1          26.5          65.1              :
            : T)                                                                                            :
            : M]                            12.7[  9.2]                                                     :
   12       :         15.6         12.0          14.5         18.4          28.0          69.3              :
            : T)                                                                                            :
            : M]                                                                                            :
   15       :         21.0         15.0          16.1         19.4          29.2          72.3              :
            : T)                                                                                            :
            : M]                                                                                            :
   20       :         31.3         20.8          18.6         21.0          31.0          76.6              :
            : T)                                                                                            :
            : M]                                                                                            :
   25       :         43.4         27.3          21.0         22.3          32.5          80.2              :
            : T)                                                                                            :
            : M]   63.5[ 32.5]  30.7[ 27.5]                                                                 :
   33       :         65.3         37.2          24.8         24.4          34.6          84.9              :
            : T)                                                                                            :
            : M]                                                                                            :
   42       :         85.6         46.5          28.8         26.5          36.6          89.4              :
            : T)                                                                                            :
            : M]                                                                                            :
   54       :        110.0         58.4          34.0         29.2          38.8          94.4              :
            : T)                                                                                            :
            : M]                                                                                            :
   70       :        141.0         73.9          41.0         32.8          41.6         100.0              :
            : T)                                                                                            :
            : M]                                                                                            :
   90       :        176.0         92.2          49.5         37.0          44.4         106.0              :
            : T) 193.0(101.0)                                                        111.0(109.0)           :
            : M]                                                                                            :
  115       :        214.0        114.0          59.8         42.1          47.6         113.0              :
            : T)              133.0(140.0)                                                                  :
            : M]                                                                                            :
  148       :                     139.0          72.6         48.6          51.6         122.0              :
            : T)                                                                                            :
            : M]                                                                                            :
  190       :                     163.0          87.6         56.5          56.2                            :
            : T)                            88.9(194.0)  64.6(237.0)  59.0(218.0)                           :
            : M]                                                                                            :
  244       :                                   104.0         65.7          61.5                            :
            : T)                                                                                            :
            : M]                                                                                            :
            -------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 239.0(140.0) 166.0(203.0) 112.0(290.0)  73.9(300.0)  66.6(300.0) 132.0(180.0)
```

TABLE 60

DIFFUSER PLUME DILUTION
PORT SPACING = 10 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.00

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	: M]				10.1[0.9]	10.1[0.1]	10.1[0.0]
1	:	1.9	2.7	5.3	10.6	17.3	42.2
	: M]						
2	:	2.7	3.5	6.7	12.4	19.7	48.5
	: M]						
3	:	3.6	4.3	7.7	13.5	21.3	52.3
	: M]						
4	:	4.6	5.0	8.7	14.4	22.5	55.7
	: M]						
5	:	5.7	5.8	9.5	15.0	23.6	58.0
	: M]						
7	:	8.1	7.4	11.1	16.2	25.1	62.2
	: M]						
9	:	10.9	9.1	12.6	17.1	26.3	65.1
	: M]			12.7[9.2]			
12	:	15.7	12.0	14.5	18.4	28.0	68.9
	: M]						
15	:	21.0	15.0	16.1	19.3	29.2	72.0
	: M]						
20	:	31.3	20.8	18.6	21.0	31.0	76.3
	: M]						
25	:	43.4	27.3	21.0	22.3	32.6	79.9
	: M]	64.8[32.9]	30.9[27.6]				
33	:	65.3	37.2	24.7	24.4	34.6	84.5
	: M]						
42	:	86.7	47.1	28.8	26.5	36.5	88.6
	: M]						
54	:	113.0	59.3	34.3	29.2	38.8	93.1
	: M]						
70	:	146.0	75.5	41.3	32.9	41.3	98.1
	: M]						
90	:	188.0	95.0	50.2	37.3	44.2	103.0
	: M]						
115	:	239.0	120.0	61.3	42.5	47.4	108.0
	: M]						
148	:	306.0	152.0	76.0	49.5	51.3	114.0
	: M]						
190	:		193.0	94.3	58.5	55.9	120.0 :I
	: M]						
244	:		246.0	118.0	69.9	61.6	126.0
	: M]						
DIL AT MAX REAL OR PERMITTED RISE		371.0(180.0)	288.0(287.0)	143.0(301.0)	81.8(300.0)	67.2(300.0)	132.0(300.0)

TABLE 61

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.10

```
                                  DENSIMETRIC FROUDE NUMBER

                    1           3           10          30          100          1000
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)
           : M)                                                                                 :
                                                                           71.0[  0.0]   :
    1      :       1.9         2.8         6.4         16.4        51.6         258.0          :
           : T)                                                              261.0(  1.1)   :
           : M)                                                                                 :
                                                               71.0[  1.9]                    :
    2      :       2.7         3.7         8.8         23.3        72.9                         :
           : T)                                                                                 :
           : M)                                                                                 :
    3      :       3.5         4.6         11.1        29.4        88.6                         :
           : T)                                                    92.3(  3.3)                  :
           : M)                                                                                 :
    4      :       4.5         5.6         13.5        35.7        103.0                        :
           : T)                                                                                 :
           : M)                                                                                 :
    5      :       5.6         6.6         16.1        42.2        123.0                        :
           : T)                                        53.0(  6.5)                              :
           : M)                                                                                 :
    7      :       8.1         8.8         22.2        57.2                                     :
           : T)                                                                                 :
           : M)                                        71.5[  8.6]                              :
    9      :       10.8        11.3        29.6        75.5                                     :
           : T)                            38.0( 10.8)                                          :
           : M)                                                                                 :
   12      :       15.4        15.8        44.9                                                 :
           : T)                                                                                 :
           : M)                                                                                 :
   15      :       20.5        21.4                                                             :
           : T)  25.5( 17.6) 26.2( 17.0)                                                        :
           : M)                                                                                 :
   20      :       30.7        37.3                                                             :
           : T)                                                                                 :
           : M)                                                                                 :
           ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  67.2( 23.4)  63.3( 22.2)  66.1( 14.7)  83.2(  9.4) 128.0(  5.1) 361.0(  1.7)
```

TABLE 62

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.10

```
                                         DENSIMETRIC FROUDE NUMBER

                       1           3          10          30         100        1000
RISE(DIA)   ----------------------------------------------------------------------------------
            : T)                                                                             :
            : M]                                                                71.0[  0.0]  :
     1      :        1.9         2.8         6.4        16.4        51.2       249.0         :
            : T)                                                                             :
            : M]                                                    71.0[  2.0]              :
     2      :        2.7         3.7         8.8        23.1        71.9       319.0         :
            : T)                                                               326.0(  2.1)  :
            : M]                                                                             :
     3      :        3.6         4.6        11.0        29.0        86.1       390.0         :
            : T)                                                                             :
            : M]                                                                             :
     4      :        4.5         5.6        13.4        35.2        97.6                     :
            : T)                                                                             :
            : M]                                                                             :
     5      :        5.6         6.6        16.0        41.3       108.0                     :
            : T)                                                   121.0(  6.2)              :
            : M]                                                                             :
     7      :        8.1         8.8        21.7        54.9       130.0                     :
            : T)                                                                             :
            : M]                                                                             :
     9      :       10.9        11.2        28.6        70.0       153.0                     :
            : T)                                        85.0( 11.0)                          :
            : M]                                        71.5[  9.2]                          :
    12      :       15.6        15.6        41.6        93.0                                 :
            : T)                                                                             :
            : M]                                                                             :
    15      :       21.0        20.7        58.0       117.0                                 :
            : T)                            69.5( 16.7)                                      :
            : M]                            73.5[ 17.3]                                      :
    20      :       31.1        31.3        94.3                                             :
            : T)                                                                             :
            : M]                                                                             :
    25      :       43.1        46.5                                                         :
            : T)    45.6( 26.0) 48.8( 25.6)                                                  :
            : M]                82.7[ 30.5]                                                  :
    33      :       72.5                                                                     :
            : T)                                                                             :
            : M]    90.5[ 33.7]                                                              :
            ----------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 126.0( 34.0) 118.0( 32.3) 114.0( 22.1) 125.0( 15.7) 168.0(  9.6) 452.0(  3.4)
```

TABLE 63

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                  DENSIMETRIC FROUDE NUMBER

                    1              3              10             30             100            1000
RISE(DIA)  -----------------------------------------------------------------------------------------------:
           : T)                                                                           71.0[  0.0]    :
           : M)                                                                50.9        245.0         :
    1      :        1.9            2.8            6.4            16.4                                    :
           : T)                                                          71.0[  2.0]                     :
           : M)                                                                            306.0         :
    2      :        2.7            3.7            8.8            22.9                                    :
           : T)                                                                                          :
           : M)                                                                85.0        352.0         :
    3      :        3.6            4.6            11.0           29.0                                    :
           : T)                                                                                          :
           : M)                                                                96.2        391.0         :
    4      :        4.5            5.6            13.4           35.0                                    :
           : T)                                                                                          :
           : M)                                                  41.0          106.0       425.0         :
    5      :        5.6            6.6            15.9                                    458.0(  6.0)   :
           : T)                                                                                          :
           : M)                                                                124.0       492.0         :
    7      :        8.1            8.7            21.5           54.2                                    :
           : T)                                                                                          :
           : M)                                                                142.0       573.0         :
    9      :        10.9           11.2           28.2           68.5                                    :
           : T)                                                71.4[  9.4]                               :
           : M)                                                  90.4          166.0                     :
   12      :        15.7           15.5           40.2                                                   :
           : T)                                                                                          :
           : M)                                                  111.0         191.0                     :
   15      :        21.1           20.4           55.3                       197.0( 15.8)                :
           : T)                                 75.5[ 18.4]                                              :
           : M)                                   86.2           146.0         232.0                     :
   20      :        31.5           30.5                        166.0( 23.1)                              :
           : T)                                                                                          :
           : M)                                   119.0          181.0                                   :
   25      :        44.0           42.8         155.0( 30.5)                                             :
           : T)                                                                                          :
           : M)                                   174.0                                                  :
   33      :        67.1           69.5                                                                  :
           : T)                                                                                          :
           : M)                109.0[ 41.2]                                                              :
   42      :        98.3           114.0                                                                 :
           : T) 112.0( 45.5) 129.0( 44.4)                                                                :
           : M)                                                                                          :
   54      :        157.0          239.0                                                                 :
           : T)                                                                                          :
           : M) 159.0[ 54.4]                                                                             :
           -----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 312.0( 58.3) 270.0( 55.1) 236.0( 40.6) 238.0( 37.7) 275.0( 24.1) 617.0(  9.6)
```

TABLE 64

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                 DENSIMETRIC FROUDE NUMBER

                      1           3           10           30           100          1000
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)                                                                              :
           : M]                                                                 71.0[  0.0]  :
    1      :         1.9         2.8         6.4          16.4         50.9      244.0       :
           : T)                                                                              :
           : M]                                                    71.0[  2.0]               :
    2      :         2.7         3.7         8.8          22.9                   304.0       :
           : T)                                                                              :
           : M]                                                                              :
    3      :         3.6         4.6        11.0          29.0         84.4      347.0       :
           : T)                                                                              :
           : M]                                                                              :
    4      :         4.5         5.6        13.4          35.0         95.6      380.0       :
           : T)                                                                              :
           : M]                                                                              :
    5      :         5.6         6.6        15.9          41.0        105.0      411.0       :
           : T)                                                                              :
           : M]                                                                              :
    7      :         8.1         8.7        21.5          54.1        124.0      461.0       :
           : T)                                                                              :
           : M]                                                                              :
    9      :        10.9        11.2        28.0          68.1        141.0      505.0       :
           : T)                                                                              :
           : M]                                      71.4[  9.5]                             :
   12      :        15.7        15.5        39.9          69.8        164.0      563.0       :
           : T)                                                                              :
           : M]                                                                              :
   15      :        21.1        20.4        54.5         111.0        187.0      615.0       :
           : T)                                                                              :
           : M]                         76.0[ 18.7]                                          :
   20      :        31.8        30.3        84.4         144.0        225.0                  :
           : T)                                                                              :
           : M]                                                                              :
   25      :        44.0        42.5       115.0         177.0        261.0                  :
           : T)                                                                              :
           : M]                                                                              :
   33      :        67.6        67.1       164.0         230.0        317.0                  :
           : T)                                                                              :
           : M]                                                                              :
   42      :        99.0       103.0       219.0         289.0        381.0                  :
           : T)                                     364.0( 53.2) 387.0( 43.0)                :
           : M]           124.0[ 46.1]                                                       :
   54      :       150.0       163.0       297.0         369.0                               :
           : T)                           355.0( 62.6)                                       :
           : M]                                                                              :
   70      :       234.0       244.0       408.0                                             :
           : T) 309.0( 83.7) 318.0( 82.4)                                                    :
           : M] 247.0[ 72.4]                                                                 :
   90      :       343.0       379.0                                                         :
           : T)                                                                              :
           : M]                                                                              :
           ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 447.0(103.0) 510.0( 99.9) 462.0( 77.1) 453.0( 66.5) 461.0( 53.4) 629.0( 15.9)
```

TABLE 65

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.10

```
                                     DENSIMETRIC FROUDE NUMBER

                          1            3            10           30           100          1000
RISE(DIA)   ------------------------------------------------------------------------------------------
            : M]
    1       :            1.9          2.8          6.4          16.4          50.9      71.0[  0.0]  :
            : M]                                                         71.0[  2.0]     244.0       :
    2       :            2.7          3.7          8.8          22.9                                 :
            : M]                                                                         302.0       :
    3       :            3.6          4.6         11.0          28.8          84.4                   :
            : M]                                                                         345.0       :
    4       :            4.5          5.6         13.4          34.8          95.6                   :
            : M]                                                                         378.0       :
    5       :            5.6          6.6         15.9          41.0         105.0                   :
            : M]                                                                         407.0       :
    7       :            8.1          8.7         21.4          53.8         124.0                   :
            : M]                                                                         456.0       :
    9       :           10.9         11.2         28.0          68.1         140.0                   :
            : M]                                             71.4[  9.5]                 497.0       :
   12       :           15.7         15.3         39.9          89.8         164.0                   :
            : M]                                                                         550.0       :
   15       :           21.1         20.4         54.1         110.0         187.0                   :
            : M]                                76.6[ 18.9]                              595.0       :
   20       :           31.8         30.3         83.8         144.0         223.0                   :
            : M]                                                                                     :
   25       :           44.3         42.2        114.0         177.0         259.0                   :
            : M]                                                                                     :
   33       :           67.6         66.7        162.0         228.0         315.0                   :
            : M]                                                                                     :
   42       :           99.6        102.0        215.0         287.0         377.0                   :
            : M]                   129.0[ 47.7]                                                      :
   54       :          151.0        160.0        284.0         364.0         458.0                   :
            : M]                                                                                     :
   70       :          234.0        232.0        378.0         468.0                                 :
            : M] 289.0[ 79.2]                                                                        :
   90       :          352.0        321.0        495.0                                               :
            : M]                                                                                     :
  115       :          487.0        431.0                                                            :
            : M]                                                                                     :
            ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 535.0(124.0) 487.0(128.0) 528.0( 95.9) 541.0( 81.6) 536.0( 65.9) 633.0( 17.9)
```

TABLE 66

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.05

```
                                      DENSIMETRIC FROUDE NUMBER

                        1            3             10            30            100           1000
RISE(DIA)  --------------------------------------------------------------------------------------------
           : T)
           : M]                                                                                       :
    1      :            1.9          2.8           5.9           13.7                    44.9[  0.0)  :
           : T)                                                                40.5       172.0       :
           : M]                                                                          195.0(  1.4)  :
    2      :            2.7          3.6           7.6           18.6        44.9[  1.3]               :
           : T)                                                                54.5       232.0       :
           : M]                                                                                       :
    3      :            3.6          4.4           9.1           22.5                                  :
           : T)                                                                63.5                   :
           : M]                                                              71.0(  4.0)               :
    4      :            4.6          5.1          10.3           26.2          71.5                   :
           : T)                                                                                       :
           : M]                                                                                       :
    5      :            5.6          6.0          11.7           29.8          78.7                   :
           : T)                                                                                       :
           : M]                                                                                       :
    7      :            8.1          7.6          14.3           37.8                                  :
           : T)                                                41.3(  7.8)                             :
           : M]                                                45.2[  8.7]                             :
    9      :           10.8          9.4          17.3           46.8                                  :
           : T)                                                                                       :
           : M]                                                                                       :
   12      :           15.4         12.3          22.3                                                :
           : T)                                26.0( 13.8)                                            :
           : M]                                                                                       :
   15      :           20.3         15.5          29.0                                                :
           : T)  24.9( 17.7)  20.5( 19.2)                                                             :
           : M]                                45.6[ 19.1]                                            :
   20      :           29.3         21.7                                                              :
           : T)                                                                                       :
           : M]  49.2[ 23.9]                                                                          :
   25      :                        30.9                                                              :
           : T)                                                                                       :
           : M]               45.6[ 26.4]                                                             :
           --------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  56.1( 23.9)  46.2( 26.4)  48.5( 19.4)  62.6( 11.7)  97.2(  6.4) 269.0(  2.3)
```

TABLE 67

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.05

```
                                       DENSIMETRIC FROUDE NUMBER

                      1            3            10           30           100          1000
RISE(DIA)   -------------------------------------------------------------------------------------
            : T)
            : M]                                                                                 :
    1       :        1.9          2.8          5.9          13.7                   44.9[  0.0]  :
            : T)                                                        40.2        169.0        :
            : M]                                                                                 :
    2       :        2.7          3.6          7.6          18.5       44.9[  1.3]               :
            : T)                                                        53.8        214.0        :
            : M]                                                                    242.0(  2.8)  :
    3       :        3.6          4.4          9.0          22.3        62.2        249.0        :
            : T)                                                                                 :
            : M]                                                                                 :
    4       :        4.6          5.1          10.3         25.8        69.0        289.0        :
            : T)                                                                                 :
            : M]                                                                                 :
    5       :        5.7          6.0          11.6         29.4        75.0                     :
            : T)                                                                                 :
            : M]                                                                                 :
    7       :        8.1          7.6          14.2         36.5        86.2                     :
            : T)                                                       90.4(  7.8)               :
            : M]                                                                                 :
    9       :       10.9          9.4          16.9         44.3        96.9                     :
            : T)                                                                                 :
            : M]                                           45.5[  9.4]                           :
   12       :       15.5         12.3          21.4         55.7        116.0                    :
            : T)                                           62.6( 13.9)                           :
            : M]                                                                                 :
   15       :       20.8         15.6          26.5         67.1                                 :
            : T)                                                                                 :
            : M]                                                                                 :
   20       :       30.7         21.6          37.3         89.2                                 :
            : T)                                45.2( 22.8)                                      :
            : M]                                51.2[ 24.6]                                      :
   25       :       41.3         28.6          53.1                                              :
            : T)  44.0( 26.2)  36.2( 29.9)                                                       :
            : M]                                                                                 :
   33       :       59.6         42.2                                                            :
            : T)                                                                                 :
            : M]  71.2[ 34.9]  61.0[ 38.7]                                                       :
            -------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 108.0( 35.1)  89.1( 39.9)  84.4( 30.7)  91.6( 20.2) 124.0( 12.4) 335.0(  4.5)
```

TABLE 68

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                                  DENSIMETRIC FROUDE NUMBER

                               1                 3               10                30                100             1000
RISE(DIA)       ---------------------------------------------------------------------------------------------------------------------
                : T)                                                                                                                :
                : M]                                                                                              44.9[  0.0]       :
      1         :             1.9               2.8               5.9              13.7              39.9             168.0         :
                : T)                                                                                                                :
                : M]                                                                            44.9[  1.3]                         :
      2         :             2.7               3.6               7.6              18.5              53.4             208.0         :
                : T)                                                                                                                :
                : M]                                                                                                                :
      3         :             3.6               4.4               9.0              22.2              61.3             237.0         :
                : T)                                                                                                                :
                : M]                                                                                                                :
      4         :             4.6               5.1              10.3              25.6              68.1             261.0         :
                : T)                                                                                                                :
                : M]                                                                                                                :
      5         :             5.7               6.0              11.6              29.0              74.0             282.0         :
                : T)                                                                                                                :
                : M]                                                                                                                :
      7         :             8.1               7.6              14.1              36.0              83.8             320.0         :
                : T)                                                                                             339.0(  8.0)       :
                : M]                                                                                                                :
      9         :            10.9               9.4              16.7              43.4              93.6             357.0         :
                : T)                                                                                                                :
                : M]                                                           45.9[  9.7]                                          :
     12         :            15.6              12.3              21.0              54.2             107.0             420.0         :
                : T)                                                                                                                :
                : M]                                                                                                                :
     15         :            21.0              15.6              25.8              64.4             119.0                           :
                : T)                                                                                                                :
                : M]                                                                                                                :
     20         :            31.3              21.7              35.0              80.9             140.0                           :
                : T)                                                                           143.0( 20.9)                         :
                : M]                                                                                                                :
     25         :            43.1              28.6              45.9              97.6             160.0                           :
                : T)                                                          118.0( 30.8)                                          :
                : M]                                         57.2[ 29.3]                                                            :
     33         :            64.4              41.6              67.6             126.0                                             :
                : T)                                                                                                                :
                : M]                                                                                                                :
     42         :            91.1              58.9              93.6             161.0                                             :
                : T) 105.0( 46.4)                           102.0( 44.5)                                                            :
                : M]                                                                                                                :
     54         :           130.0              87.4             144.0                                                               :
                : T)                        88.6( 54.6)                                                                             :
                : M] 143.0[ 57.7]           99.7[ 58.5]                                                                             :
     70         :                           167.0                                                                                   :
                : T)                                                                                                                :
                : M]                                                                                                                :
                ---------------------------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 274.0( 61.2) 222.0( 71.0) 183.0( 59.0) 173.0( 44.3) 200.0( 32.4) 471.0( 13.0)
```

TABLE 69

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.05

```
                                      DENSIMETRIC FROUDE NUMBER

                     1             3             10            30            100           1000
RISE(DIA)   -----------------------------------------------------------------------------------------
            : T)                                                                                    :
            : M]                                                                 44.9[  0.0]        :
    1       :        1.9           2.8           5.9          13.7          39.9       168.0         :
            : T)                                                                                    :
            : M]                                                    44.9[  1.3]                     :
    2       :        2.7           3.6           7.6          18.5          53.4       206.0         :
            : T)                                                                                    :
            : M]                                                                                    :
    3       :        3.6           4.4           9.0          22.2          61.3       234.0         :
            : T)                                                                                    :
            : M]                                                                                    :
    4       :        4.6           5.1          10.3          25.6          67.6       258.0         :
            : T)                                                                                    :
            : M]                                                                                    :
    5       :        5.7           6.0          11.6          29.0          73.5       277.0         :
            : T)                                                                                    :
            : M]                                                                                    :
    7       :        8.1           7.6          14.0          36.0          83.2       309.0         :
            : T)                                                                                    :
            : M]                                                                                    :
    9       :       10.9           9.4          16.7          43.1          92.3       337.0         :
            : T)                                                                                    :
            : M]                                        45.9[  9.8]                                 :
   12       :       15.7          12.3          21.0          53.8         105.0       372.0         :
            : T)                                                                                    :
            : M]                                                                                    :
   15       :       21.0          15.6          25.6          63.9         118.0       404.0         :
            : T)                                                                                    :
            : M]                                                                                    :
   20       :       31.3          21.7          34.5          79.8         137.0       451.0         :
            : T)                                                                                    :
            : M]                                                                                    :
   25       :       43.4          28.8          44.9          95.6         156.0       495.0         :
            : T)                                                                                    :
            : M]                          59.7[ 31.1]                                               :
   33       :       65.3          41.6          64.8         121.0         185.0                     :
            : T)                                                                                    :
            : M]                                                                                    :
   42       :       94.3          58.8          87.4         149.0         217.0                     :
            : T)                                                                                    :
            : M]                                                                                    :
   54       :      139.0          86.2         117.0         188.0         260.0                     :
            : T)                                                      277.0( 58.8)                  :
            : M]           130.0[ 69.8]                                                             :
   70       :      205.0       131.0           157.0         241.0         318.0                     :
            : T) 279.0( 87.3)                            255.0( 74.2)                               :
            : M] 248.0[ 79.5]                                                                       :
   90       :      290.0       184.0           215.0         312.0                                   :
            : T)           223.0(105.0) 232.0( 95.2)                                                :
            : M]                                                                                    :
  115       :                  249.0           326.0                                                 :
            : T)                                                                                    :
            : M]                                                                                    :
            -----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 361.0(111.0) 375.0(136.0) 388.0(123.0) 350.0( 99.6) 353.0( 79.7) 506.0( 26.4)
```

TABLE 70

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.05

DENSIMETRIC FROUDE NUMBER

RISE(DIA)		1	3	10	30	100	1000
	M]						44.9[0.0]
1		1.9	2.8	5.9	13.7	39.9	168.0
	M]					44.9[1.3]	
2		2.7	3.6	7.6	18.5	53.4	206.0
	M]						
3		3.6	4.4	9.0	22.2	61.3	234.0
	M]						
4		4.6	5.1	10.3	25.6	67.6	256.0
	M]						
5		5.7	6.0	11.6	29.0	73.5	275.0
	M]						
7		8.1	7.6	14.0	36.0	83.2	306.0
	M]						
9		10.9	9.4	16.7	43.1	92.3	333.0
	M]				45.9[9.8]		
12		15.7	12.3	21.0	53.8	105.0	366.0
	M]						
15		21.1	15.6	25.4	63.5	117.0	396.0
	M]						
20		31.5	21.7	34.3	79.8	136.0	436.0
	M]						
25		43.4	28.8	44.6	94.9	155.0	472.0
	M]			60.5[31.6]			
33		65.7	41.9	64.4	119.0	183.0	
	M]						
42		94.9	59.3	86.1	147.0	215.0	
	M]						
54		141.0	86.1	114.0	183.0	257.0	
	M]						
70		212.0	131.0	151.0	231.0	310.0	
	M]	299.0[87.0]	139.0[72.9]				
90		316.0	187.0	196.0	290.0	378.0	
	M]						
115		429.0	252.0	251.0	365.0		
	M]						
148			337.0	326.0			
	M]						
DIL AT MAX REAL OR PERMITTED RISE		503.0(132.0)	408.0(176.0)	386.0(175.0)	422.0(135.0)	428.0(105.0)	512.0(31.4)

TABLE 71

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.02

```
                                DENSIMETRIC FROUDE NUMBER

                        1            3           10           30        100           1000
  RISE(DIA) --------------------------------------------------------------------------------------
            : T)                                                                                 :
            : M]                                                                    32.0[  0.0]  :
      1     :        1.9          2.7          5.5         11.9         30.5        111.0        :
            : T)                                                                   138.0(  2.0)  :
            : M]                                                       32.0[  1.1]               :
      2     :        2.7          3.6          7.1         15.5         39.1        140.0        :
            : T)                                                                                 :
            : M]                                                                                 :
      3     :        3.6          4.3          8.2         18.2         44.3        171.0        :
            : T)                                                                                 :
            : M]                                                                                 :
      4     :        4.6          5.1          9.3         20.5         48.5                     :
            : T)                                                                                 :
            : M]                                                                                 :
      5     :        5.7          5.9         10.2         22.6         52.7                     :
            : .)                                                       53.0(  5.2)               :
            : M]                                                                                 :
      7     :        8.1          7.5         12.0         26.5         60.5                     :
            : T)                                                                                 :
            : M]                                                                                 :
      9     :       10.8          9.2         13.7         30.5                                  :
            : T)                                          31.5(  9.5)                            :
            : M]                                          32.9[ 10.2]                            :
     12     :       15.2         12.0         16.2         36.7                                  :
            : T)                                                                                 :
            : M]                                                                                 :
     15     :       20.3         14.9         19.0                                               :
            : T)   24.8( 17.6)  19.7( 19.6)  19.8( 16.0)                                         :
            : M]                                                                                 :
     20     :       29.0         20.1         24.4                                               :
            : T)                                                                                 :
            : M]   39.3[ 24.0]               32.5[ 23.7]                                         :
     25     :                    25.6                                                            :
            : T)                                                                                 :
            : M]                33.4[ 27.5]                                                      :
            --------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  45.5( 24.0)  34.8( 27.6)  33.3( 23.8)  45.0( 14.7)  70.4(  8.3) 187.0(  3.2)
```

TABLE 72

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.02

```
                            DENSIMETRIC FROUDE NUMBER

                       1           3          10          30         100        1000
 RISE(DIA)  ------------------------------------------------------------------------------------
            : T)                                                                              :
            : M)                                                            32.0[  0.0]       :
      1     :        1.9         2.7         5.5        11.9        30.5       109.0          :
            : T)                                                                              :
            : M)                                                32.0[  1.1]                   :
      2     :        2.7         3.6         7.1        15.5        38.8       134.0          :
            : T)                                                                              :
            : M)                                                                              :
      3     :        3.6         4.3         8.2        18.1        43.7       153.0          :
            : T)                                                            169.0(  4.0)      :
            : M)                                                                              :
      4     :        4.6         5.1         9.3        20.4        47.5       170.0          :
            : T)                                                                              :
            : M)                                                                              :
      5     :        5.7         5.9        10.2        22.3        50.9       188.0          :
            : T)                                                                              :
            : M)                                                                              :
      7     :        8.1         7.5        11.9        25.8        56.5                      :
            : T)                                                                              :
            : M)                                                                              :
      9     :       10.9         9.2        13.5        29.2        61.8                      :
            : T)                                                64.8( 10.4)                   :
            : M)                                    33.6[ 11.6]                               :
     12     :       15.5        12.0        16.0        34.3        69.0                      :
            : T)                                                                              :
            : M)                                                                              :
     15     :       20.7        15.1        18.5        38.8        77.2                      :
            : T)                                    42.8( 17.9)                               :
            : M)                                                                              :
     20     :       30.5        20.7        22.9        46.2                                  :
            : T)                                                                              :
            : M)                                                                              :
     25     :       41.3        26.9        27.9        54.8                                  :
            : T)  43.7( 26.2) 34.1( 30.7) 30.9( 28.1)                                         :
            : M)                                                                              :
     33     :       58.4        37.3        37.0                                              :
            : T)                                                                              :
            : M)  64.1[ 35.1] 50.0[ 41.3] 40.8[ 35.5]                                         :
     42     :                   57.5                                                          :
            : T)                                                                              :
            : M)                                                                              :
            ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  90.0( 35.3)  66.5( 42.1)  56.3( 40.3)  61.8( 27.3)  87.3( 16.9) 231.0(  6.5)
```

TABLE 73

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.02

```
                          DENSIMETRIC FROUDE NUMBER

                   1             3            10            30           100          1000
RISE(DIA) -------------------------------------------------------------------------------------------
          : T)                                                                                      :
          : M]                                                                  32.0[  0.0]         :
    1     :       1.9           2.7           5.5          11.9          30.5     109.0             :
          : T)                                                                                      :
          : M]                                                    32.0[  1.1]                       :
    2     :       2.7           3.6           7.1          15.3          38.6     132.0             :
          : T)                                                                                      :
          : M]                                                                                      :
    3     :       3.6           4.3           8.2          18.0          43.4     149.0             :
          : T)                                                                                      :
          : M]                                                                                      :
    4     :       4.6           5.1           9.3          20.2          47.1     163.0             :
          : T)                                                                                      :
          : M]                                                                                      :
    5     :       5.7           5.9          10.1          22.2          50.7     175.0             :
          : T)                                                                                      :
          : M]                                                                                      :
    7     :       8.1           7.5          11.9          25.6          55.7     195.0             :
          : T)                                                                                      :
          : M]                                                                                      :
    9     :      10.9           9.2          13.5          28.8          60.1     213.0             :
          : T)                                                                    233.0( 11.5)      :
          : M]                                                                                      :
   12     :      15.6          12.0          15.9          33.3          65.7     236.0             :
          : T)                                                                                      :
          : M]                                      34.0[ 12.5]                                     :
   15     :      21.0          15.1          18.4          37.5          71.4     264.0             :
          : T)                                                                                      :
          : M]                                                                                      :
   20     :      31.1          21.0          22.6          43.7          80.0                       :
          : T)                                                                                      :
          : M]                                                                                      :
   25     :      42.8          27.5          27.3          49.5          88.3                       :
          : T)                                                    95.2( 29.4)                       :
          : M]                                                                                      :
   33     :      64.0          38.8          35.2          58.4         101.0                       :
          : T)                                                                                      :
          : M]                                                                                      :
   42     :      90.4          53.4          45.5          69.0         118.0                       :
          : T) 104.0( 46.4)                             72.2( 44.7)                                 :
          : M]                        54.5[ 49.4]                                                   :
   54     :     127.0          74.5          60.1          85.7                                     :
          : T)           79.8( 57.0)   66.6( 59.7)                                                  :
          : M] 139.0[ 58.1]  94.6[ 65.0]                                                            :
   70     :                 103.0          79.4                                                     :
          : T)                                                                                      :
          : M]                                                                                      :
          -------------------------------------------------------------------------------------------

DIL. AT MAX REAL
OR PERMITTED RISE 244.0( 61.6) 175.0( 76.7) 130.0( 82.7) 115.0( 66.3) 132.0( 46.8) 321.0( 18.8)
```

TABLE 74

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.02

```
                                DENSIMETRIC FROUDE NUMBER

                 1          3          10          30          100        1000
RISE(DIA)  ----------------------------------------------------------------------
           : T)                                                                 :
           : M]                                                  32.0[  0.0]    :
    1      :    1.9        2.7         5.5        11.9        30.5   108.0       :
           : T)                                                                 :
           : M]                                         32.0[  1.1]             :
    2      :    2.7        3.6         7.1        15.3        38.6      132.0    :
           : T)                                                                 :
           : M]                                                                 :
    3      :    3.6        4.3         8.2        18.0        43.4      148.0    :
           : T)                                                                 :
           : M]                                                                 :
    4      :    4.6        5.1         9.3        20.2        47.1      162.0    :
           : T)                                                                 :
           : M]                                                                 :
    5      :    5.7        5.9        10.1        22.2        50.2      172.0    :
           : T)                                                                 :
           : M]                                                                 :
    7      :    8.1        7.5        11.9        25.4        55.3      191.0    :
           : T)                                                                 :
           : M]                                                                 :
    9      :   10.9        9.2        13.5        28.6        59.7      207.0    :
           : T)                                                                 :
           : M]                                                                 :
   12      :   15.6       12.0        15.9        33.1        65.3      226.0    :
           : T)                                                                 :
           : M]                              34.0[ 12.7]                        :
   15      :   21.0       15.2        18.4        37.2        70.5      244.0    :
           : T)                                                                 :
           : M]                                                                 :
   20      :   31.3       21.0        22.6        43.1        78.2      268.0    :
           : T)                                                                 :
           : M]                                                                 :
   25      :   43.4       27.5        27.1        48.5        85.7      291.0    :
           : T)                                                                 :
           : M]                                                                 :
   33      :   65.3       39.4        35.2        56.8        97.6      323.0    :
           : T)                                                   345.0( 39.1)  :
           : M]                                                                 :
   42      :   94.3       54.5        45.2        65.7       110.0      356.0    :
           : T)                                                                 :
           : M]                                                                 :
   54      :  138.0       77.6        60.1        77.4       126.0               :
           : T)                                                                 :
           : M]                   61.3[ 55.1]                                   :
   70      :  204.0      112.0        79.3        93.2       148.0               :
           : T) 276.0( 87.3)                              175.0( 89.1)          :
           : M] 246.0[ 79.5] 131.0[ 78.2]                                       :
   90      :  295.0      156.0       101.0       114.0       176.0               :
           : T)          194.0(112.0)                                           :
           : M]                                                                 :
  115      :             199.0       128.0       141.0       215.0               :
           : T)                 146.0(133.0) 147.0(120.0)                       :
           : M]                                                                 :
  148      :             248.0       163.0       191.0                           :
           : T)                                                                 :
           : M]                                                                 :
           ----------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 340.0(112.0) 259.0(152.0) 295.0(185.0) 258.0(170.0) 241.0(131.0) 374.0( 46.7)
```

TABLE 75

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.02

```
                              DENSIMETRIC FROUDE NUMBER

                     1          3         10         30        100       1000
RISE(DIA) -----------------------------------------------------------------------
          : M]                                                    32.0[  0.0]  :
    1     :        1.9        2.7        5.5       11.9       30.5      108.0  :
          : M]                                         32.0[  1.1]             :
    2     :        2.7        3.6        7.1       15.3       38.6      131.0  :
          : M]                                                                 :
    3     :        3.6        4.3        8.2       18.0       43.4      148.0  :
          : M]                                                                 :
    4     :        4.6        5.1        9.3       20.2       47.1      161.0  :
          : M]                                                                 :
    5     :        5.7        5.9       10.1       22.2       50.2      172.0  :
          : M]                                                                 :
    7     :        8.1        7.5       11.9       25.4       55.3      190.0  :
          : M]                                                                 :
    9     :       10.9        9.2       13.5       28.6       59.3      205.0  :
          : M]                                                                 :
   12     :       15.7       12.0       15.9       33.1       65.3      225.0  :
          : M]                              34.3[ 12.9]                        :
   15     :       21.0       15.2       18.2       37.2       70.0      241.0  :
          : M]                                                                 :
   20     :       31.3       21.1       22.6       43.1       78.2      264.0  :
          : M]                                                                 :
   25     :       43.4       27.7       27.1       48.5       85.3      283.0  :
          : M]                                                                 :
   33     :       65.7       39.4       35.0       56.4       96.4      310.0  :
          : M]                                                                 :
   42     :       94.9       54.9       45.2       65.3      109.0      336.0  :
          : M]                                                                 :
   54     :      140.0       78.2       60.1       76.5      124.0      367.0  :
          : M]                   63.1[ 56.4]                                   :
   70     :      211.0      114.0       79.8       91.4      144.0             :
          : M] 297.0[ 86.9] 144.0[ 81.9]                                       :
   90     :      314.0      163.0      103.0      110.0      169.0             :
          : M]                                                                 :
  115     :      423.0      217.0      129.0      132.0      199.0             :
          : M]                                                                 :
  148     :                 283.0      166.0      161.0      239.0             :
          : M]                                                                 :
  190     :                 367.0      211.0      198.0      288.0             :
          : M]                                                                 :
  244     :                            269.0      245.0                        :
          : M]                                                                 :
          ----------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 496.0(133.0) 375.0(194.0) 298.0(272.0) 273.0(276.0) 295.0(196.0) 380.0( 59.8)
```

TABLE 76

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.00

```
                                            DENSIMETRIC FROUDE NUMBER

                           1               3              10              30             100            1000
RISE(DIA)  -----------------------------------------------------------------------------------------------------------
           : T)
           : M)                                                                                         25.1(  0.0)  :
     1     :             1.9             2.7             5.3            10.6            23.6            62.2         :
           : T)                                                                                                      :
           : M)                                                                         25.3(  1.2)                  :
     2     :             2.7             3.5             6.7            13.5            28.8            71.9         :
           : T)                                                                                                      :
           : M)                                                                                                      :
     3     :             3.6             4.3             7.8            15.5            31.5            79.3         :
           : T)                                                                                         79.8(  3.2)  :
           : M)                                                                                                      :
     4     :             4.6             5.0             8.7            17.1            33.8            85.6         :
           : T)                                                                                                      :
           : M)                                                                                                      :
     5     :             5.7             5.8             9.6            18.6            35.5            93.5         :
           : T)                                                                         38.3(  6.9)                  :
           : M)                                                                                                      :
     7     :             8.1             7.4            11.2            21.3            38.6                         :
           : T)                                                                                                      :
           : M)                                                                                                      :
     9     :            10.8             9.1            12.7            23.7            41.5                         :
           : T)                                                         26.0( 11.0)                                  :
           : M)                                                         26.5( 11.5)                                  :
    12     :            15.2            11.8            14.9            27.1                                         :
           : T)                                                                                                      :
           : M)                                                                                                      :
    15     :            20.3            14.7            17.3            29.8                                         :
           : T)         24.8( 17.7)     19.6( 19.8)     18.5( 16.8)                                                  :
           : M)                                                                                                      :
    20     :            28.8            19.8            21.0                                                         :
           : T)                                                                                                      :
           : M)         34.9( 24.1)                                                                                  :
    25     :                            24.9            25.0                                                         :
           : T)                                                                                                      :
           : M)                         27.4( 27.9)     25.7( 25.5)                                                  :
           -----------------------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  34.9( 24.0)  27.5( 27.8)  26.0( 25.6)  33.3( 17.5)  47.3( 11.3)  99.9(  5.3)
```

TABLE 77

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.00

```
                                      DENSIMETRIC FROUDE NUMBER

                        1              3              10             30             100           1000
RISE(DIA)    ------------------------------------------------------------------------------------------
             : T)                                                                          25.1(  0.0)  :
             : M)                                                                          61.8         :
     1       :         1.9            2.7            5.3            10.6           23.6                 :
             : T)                                                               25.3(  1.3)             :
             : M)                                                               28.6            71.0    :
     2       :         2.7            3.5            6.7            13.4                                :
             : T)                                                                                       :
             : M)                                                                                       :
     3       :         3.6            4.3            7.7            15.5           31.3            77.1 :
             : T)                                                                                       :
             : M)                                                                                       :
     4       :         4.6            5.0            8.7            17.0           33.3            82.1 :
             : T)                                                                                       :
             : M)                                                                              86.1     :
     5       :         5.7            5.8            9.5            18.5           35.0    92.5(  6.7)  :
             : T)                                                                                       :
             : M)                                                                                       :
     7       :         8.1            7.4           11.2            21.0           37.8            93.5 :
             : T)                                                                                       :
             : M)                                                                                       :
     9       :        10.9            9.1           12.6            23.1           39.9           101.0 :
             : T)                                                                                       :
             : M)                                                                  42.6                 :
    12       :        15.5           11.9           14.9            26.2     44.3( 14.3)                :
             : T)                                                       27.5( 13.5)                     :
             : M)                                                        28.6          45.0             :
    15       :        20.7           14.9           17.1                                                :
             : T)                                                                                       :
             : M)                                                        32.0          48.9             :
    20       :        30.5           20.5           21.0          32.7( 21.5)                           :
             : T)                                                                                       :
             : M)                                                                                       :
    25       :        41.1           26.5           24.8            34.6                                :
             : T)  43.7( 26.7)  33.8( 30.9)  28.4( 29.7)                                                :
             : M)                                                                                       :
    33       :        58.0           36.8           31.1            38.6                                :
             : T)                                                                                       :
             : M)  61.4( 35.2)  46.8( 41.8)  35.9( 39.2)                                                :
    42       :                       47.0           37.6                                                :
             : T)                                                                                       :
             : M)                                                                                       :
              -------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  61.5( 35.3)  47.2( 42.6)  38.6( 43.9)  40.5( 34.7)  54.9( 24.1) 116.0( 11.4)
```

TABLE 78

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                   DENSIMETRIC FROUDE NUMBER

                      1           3            10           30          100          1000
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)                                                                               :
           : M)                                                                25.1[  0.0]    :
    1      :         1.9         2.7          5.3         10.6         23.4         61.8      :
           : T)                                                                               :
           : M)                                                   25.3[  1.3]                 :
    2      :         2.7         3.5          6.7         13.4         28.6         70.5      :
           : T)                                                                               :
           : M)                                                                               :
    3      :         3.6         4.3          7.7         15.3         31.3         76.6      :
           : T)                                                                               :
           : M)                                                                               :
    4      :         4.6         5.0          8.7         17.0         33.1         80.9      :
           : T)                                                                               :
           : M)                                                                               :
    5      :         5.7         5.8          9.5         18.4         34.8         84.4      :
           : T)                                                                               :
           : M)                                                                               :
    7      :         8.1         7.4         11.1         20.8         37.2         90.5      :
           : T)                                                                               :
           : M)                                                                               :
    9      :        10.9         9.1         12.6         22.9         39.1         95.4      :
           : T)                                                                               :
           : M)                                                                               :
   12      :        15.6        12.0         14.8         25.8         41.6        102.0      :
           : T)                                                                               :
           : M)                                      28.2[ 15.0]                              :
   15      :        21.0        15.0         17.1         28.4         43.7        107.0      :
           : T)                                                                               :
           : M)                                                                               :
   20      :        31.1        20.8         21.0         31.8         46.5        114.0      :
           : T)                                                                   116.0( 21.1) :
           : M)                                                                               :
   25      :        42.8        27.1         25.1         34.3         48.9        121.0      :
           : T)                                                                               :
           : M)                                                                               :
   33      :        64.0        38.6         31.8         38.3         52.3        134.0      :
           : T)                                                                               :
           : M)                                                                               :
   42      :        90.4        53.0         40.2         41.9         55.6                   :
           : T) 104.0( 46.4)                                        56.3( 44.1)               :
           : M)                                                                               :
   54      :       127.0        74.0         52.0         46.7         59.8                   :
           : T)              79.3( 57.3)  59.3( 63.4)  48.1( 58.3)                            :
           : M) 138.0( 58.2) 93.6( 65.3)  53.0( 55.4)                                         :
   70      :                    99.7         63.7         52.1         65.7                   :
           : T)                                                                               :
           : M)                                                                               :
   90      :                                 72.6         57.7                                :
           : T)                                                                               :
           : M)                                                                               :
           ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 143.0( 61.8) 105.0( 77.6)  73.1( 92.2)  59.4( 94.3)  70.2( 75.3) 145.0( 36.3)
```

TABLE 79

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                 DENSIMETRIC FROUDE NUMBER

                    1           3          10          30         100        1000
RISE(DIA) ---------------------------------------------------------------------------------
          : T)                                                                            :
          : M]                                                                25.1[  0.0] :
    1     :        1.9         2.7         5.3        10.6        23.4        61.3        :
          : T)                                                                            :
          : M]                                                    25.3[  1.3]             :
    2     :        2.7         3.5         6.7        13.4        28.6        70.5        :
          : T)                                                                            :
          : M]                                                                            :
    3     :        3.6         4.3         7.7        15.3        31.3        76.0        :
          : T)                                                                            :
          : M]                                                                            :
    4     :        4.6         5.0         8.7        17.0        33.1        80.4        :
          : T)                                                                            :
          : M]                                                                            :
    5     :        5.7         5.8         9.5        18.4        34.8        84.4        :
          : T)                                                                            :
          : M]                                                                            :
    7     :        8.1         7.4        11.1        20.8        37.2        90.0        :
          : T)                                                                            :
          : M]                                                                            :
    9     :       10.9         9.1        12.6        22.9        39.1        94.5        :
          : T)                                                                            :
          : M]                                                                            :
   12     :       15.6        12.0        14.8        25.6        41.3       100.0        :
          : T)                                                                            :
          : M]                                                                            :
   15     :       21.0        15.0        17.1        28.2        43.5       105.0        :
          : T)                                                                            :
          : M]                                        28.6[ 15.6]                         :
   20     :       31.3        20.8        21.0        31.5        46.2       111.0        :
          : T)                                                                            :
          : M]                                                                            :
   25     :       43.4        27.3        25.1        34.3        48.2       116.0        :
          : T)                                                                            :
          : M]                                                                            :
   33     :       65.3        39.1        32.0        38.3        51.4       123.0        :
          : T)                                                                            :
          : M]                                                                            :
   42     :       94.3        54.2        40.5        42.5        54.4       130.0        :
          : T)                                                                            :
          : M]                                                                            :
   54     :      138.0        76.6        53.0        47.4        58.0       137.0        :
          : T)                                                                            :
          : M]                            60.9[ 61.3]                                     :
   70     :      204.0       111.0        69.5        53.8        62.1       146.0        :
          : T) 275.0( 87.4)                                               151.0( 80.5)    :
          : M] 246.0[ 79.5] 131.0[ 78.7]                                                  :
   90     :      283.0       154.0        86.2        61.7        66.7       156.0        :
          : T)              189.0(113.0)                                                  :
          : M]                                                                            :
  115     :                  192.0       105.0        70.7        72.1       168.0        :
          : T)                         125.0(146.0)                                       :
          : M]                                                                            :
  149     :                  228.0       126.0        81.9        78.5                    :
          : T)                                      89.0(171.0) 80.6(160.0)               :
          : M]                                                                            :
  190     :                              148.0        94.6        86.0                    :
          : T)                                                                            :
          : M]                                                                            :
  244     :                                          107.0        94.9                    :
          : T)                                                                            :
          : M]                                                                            :
          ---------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 334.0(112.0) 232.0(154.0) 154.0(213.0) 111.0(267.0)  99.9(267.0) 173.0(123.0)
```

TABLE 80

DIFFUSER PLUME DILUTION
PORT SPACING = 25 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.00

```
                                   DENSIMETRIC FROUDE NUMBER

                       1            3            10           30           100          1000
RISE(DIA)   ------------------------------------------------------------------------------------
            : M)                                                               25.1[  0.0]   :
   1        :        1.9          2.7          5.3          10.6          23.4        61.3     :
            : M)                                                    25.3[  1.3]               :
   2        :        2.7          3.5          6.7          13.4          28.6        70.5     :
            : M)                                                                              :
   3        :        3.6          4.3          7.7          15.3          31.3        76.0     :
            : M)                                                                              :
   4        :        4.6          5.0          8.7          17.0          33.1        80.4     :
            : M)                                                                              :
   5        :        5.7          5.8          9.5          18.4          34.8        84.4     :
            : M)                                                                              :
   7        :        8.1          7.4         11.1          20.8          37.2        90.0     :
            : M)                                                                              :
   9        :       10.9          9.1         12.6          22.9          39.1        94.5     :
            : M)                                                                              :
  12        :       15.7         12.0         14.8          25.6          41.3        99.9     :
            : M)                                                                              :
  15        :       21.0         15.0         17.1          28.2          43.2       104.0     :
            : M)                                     28.6[ 15.6]                              :
  20        :       31.3         20.8         21.0          31.5          45.9       111.0     :
            : M)                                                                              :
  25        :       43.4         27.3         25.1          34.3          48.2       116.0     :
            : M)                                                                              :
  33        :       65.7         39.1         32.0          38.3          51.3       122.0     :
            : M)                                                                              :
  42        :       94.9         54.1         40.8          42.5          54.1       128.0     :
            : M)                                                                              :
  51        :      140.0         77.6         53.4          47.7          57.7       135.0     :
            : M)                        63.5[ 63.1]                                           :
  70        :      211.0        114.0         70.5          54.3          61.7       142.0     :
            : M) 297.0[ 86.9] 143.0[ 81.9]                                                    :
  90        :      313.0        162.0         88.6          62.4          66.3       149.0     :
            : M)                                                                              :
 115        :      419.0        212.0        110.0          72.7          71.6       157.0     :
            : M)                                                                              :
 148        :                   274.0        138.0          85.5          78.3       165.0     :
            : M)                                                                              :
 190        :                   351.0        172.0         102.0          86.4                 :
            : M)                                                                              :
 244        :                                216.0         123.0          96.3                 :
            : M)                                                                              :
            ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 491.0(133.0) 363.0(197.0) 262.0(300.0) 145.0(301.0) 106.0(301.0) 174.0(191.0)
```

TABLE 81

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.10

```
                                           DENSIMETRIC FROUDE NUMBER

                         1             3            10            30           100          1000
                                                                                      --------------
RISE(DIA)   ----------------------------------------------------------------------------------------
            : T)                                                                    436.0(  0.7)  :
            : M)                                                                                  :
    1       :           1.9           2.8           6.4          16.4          51.6     571.0      :
            : T)                                                                                  :
            : M)                                                                                  :
    2       :           2.7           3.7           8.8          23.3          73.5                :
            : T)                                                                                  :
            : M)                                                                                  :
    3       :           3.5           4.6          11.1          29.4          93.0                :
            : T)                                                            96.9(  .2)             :
            : M)                                                                                  :
    4       :           4.5           5.6          13.5          35.7         114.0                :
            : T)                                                                                  :
            : M)                                                                                  :
    5       :           5.6           6.6          16.1          42.2                              :
            : T)                                                53.0(  6.5)                        :
            : M)                                                                                  :
    7       :           8.1           8.8          22.2          57.2                              :
            : T)                                                                                  :
            : M)                                                                                  :
    9       :          10.8          11.3          29.6          76.1                              :
            : T)                                   38.0( 10.8)                                     :
            : M)                                                                                  :
   12       :          15.4          15.8          44.9                                            :
            : T)                                                                                  :
            : M)                                                                                  :
   15       :          20.5          21.4                                                          :
            : T)   25.5( 17.6)   26.2( 17.0)                                                       :
            : M)                                                                                  :
   20       :          30.7          37.3                                                          :
            : T)                                                                                  :
            : M)                                                                                  :
            ----------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  67.2( 23.4)  63.3( 22.2)  66.1( 14.7)  84.7(  9.4) 152.0(  4.9) 684.0(  1.1)
```

TABLE 82

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.10

```
                                DENSIMETRIC FROUDE NUMBER

                         1          3          10          30          100          1000
RISE(DIA)   ---------------------------------------------------------------------------------
            : T)                                                                            :
            : M)                                                                            :
    1       :           1.9        2.8        6.4        16.4        51.2        497.0      :
            : T)                                                                 592.0(  1.3)   :
            : M)                                                                            :
    2       :           2.7        3.7        8.8        23.1        71.9        893.0      :
            : T)                                                                            :
            : M)                                                                            :
    3       :           3.6        4.6       11.0        29.0        89.2                   :
            : T)                                                                            :
            : M)                                                                            :
    4       :           4.5        5.6       13.4        35.2       105.0                   :
            : T)                                                                            :
            : M)                                                                            :
    5       :           5.6        6.6       16.0        41.3       122.0                   :
            : T)                                                   136.0(  5.9)             :
            : M)                                                                            :
    7       :           8.1        8.8       21.7        54.9       156.0                   :
            : T)                                                                            :
            : M)                                                                            :
    9       :          10.9       11.2       28.6        70.0                               :
            : T)                                        86.2( 11.0)                         :
            : M)                                                                            :
   12       :          15.6       15.6       41.6        96.3                               :
            : T)                                                                            :
            : M)                                                                            :
   15       :          21.0       20.7       58.0       129.0                               :
            : T)                              69.5( 16.7)                                   :
            : M)                                                                            :
   20       :          31.1       31.3       97.0                                           :
            : T)                                                                            :
            : M)                                                                            :
   25       :          43.1       46.5                                                      :
            : T)   45.6( 26.0)  48.8( 25.6)                                                 :
            : M)                                                                            :
   33       :          72.5                                                                 :
            : T)                                                                            :
            : M)                                                                            :
            ---------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 128.0( 34.0) 121.0( 32.3) 120.0( 22.0) 138.0( 15.4) 215.0(  8.8) 929.0(  2.0)
```

TABLE 83

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                      DENSIMETRIC FROUDE NUMBER

                     1          3          10          30          100          1000
RISE(DIA)  -----------------------------------------------------------------------------
           : T)                                                                       :
           : M)                                                                       :
   1       :        1.9        2.8         6.4        16.4         50.9        477.0  :
           : T)                                                                       :
           : M)                                                                       :
   2       :        2.7        3.7         8.8        22.9         71.0        689.0  :
           : T)                                                                       :
           : M)                                                                       :
   3       :        3.6        4.6        11.0        29.0         87.3        867.0  :
           : T)                                                          929.0(  3.4) :
           : M)                                                                       :
   4       :        4.5        5.6        13.4        35.0        102.0               :
           : T)                                                                       :
           : M)                                                                       :
   5       :        5.6        6.6        15.9        41.0        117.0               :
           : T)                                                                       :
           : M)                                                                       :
   7       :        8.1        8.7        21.5        54.2        147.0               :
           : T)                                                                       :
           : M)                                                                       :
   9       :       10.9       11.2        28.2        68.5        176.0               :
           : T)                                                                       :
           : M)                                                                       :
  12       :       15.7       15.5        40.2        92.3        224.0               :
           : T)                                             254.0( 13.8)              :
           : M)                                                                       :
  15       :       21.1       20.4        55.3       120.0        277.0               :
           : T)                                                                       :
           : M)                                                                       :
  20       :       31.5       30.5        86.8       173.0                            :
           : T)                                197.0( 22.0)                           :
           : M)                                                                       :
  25       :       44.0       42.8       129.0       236.0                            :
           : T)                    178.0( 29.8)                                       :
           : M)                                                                       :
  33       :       67.1       69.5       218.0                                        :
           : T)                                                                       :
           : M)                                                                       :
  42       :       98.3      114.0                                                    :
           : T) 112.0( 45.5) 132.0( 44.3)                                             :
           : M)                                                                       :
  54       :      157.0      303.0                                                    :
           : T)                                                                       :
           : M)                                                                       :
           -----------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 326.0( 58.2) 310.0( 54.2) 297.0( 38.1) 314.0( 29.8) 402.0( 20.0) 974.0(  3.6)
```

TABLE 84

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.10

```
                                      DENSIMETRIC FROUDE NUMBER

                       1            3            10           30           100          1000
RISE(DIA)  -------------------------------------------------------------------------------------
           : T)                                                                                 :
           : M)                                                                                 :
    1      :          1.9          2.8          6.4         16.4         50.9        474.0      :
           : T)                                                                                 :
           : M)                                                                                 :
    2      :          2.7          3.7          8.8         22.9         71.0        670.0      :
           : T)                                                                                 :
           : M)                                                                                 :
    3      :          3.6          4.6         11.0         29.0         87.3        819.0      :
           : T)                                                                                 :
           : M)                                                                                 :
    4      :          4.5          5.6         13.4         35.0        102.0        954.0      :
           : T)                                                                                 :
           : M)                                                                                 :
    5      :          5.6          6.6         15.9         41.0        116.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
    7      :          8.1          8.7         21.5         54.1        145.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
    9      :         10.9         11.2         28.0         68.1        173.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
   12      :         15.7         15.5         39.9         91.7        218.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
   15      :         21.1         20.4         54.5        118.0        265.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
   20      :         31.8         30.3         85.0        170.0        351.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
   25      :         44.0         42.5        124.0        230.0        444.0                   :
           : T)                                                     611.0( 32.9)                :
           : M)                                                                                 :
   33      :         67.6         67.1        203.0        344.0        613.0                   :
           : T)                                                                                 :
           : M)                                                                                 :
   42      :         99.0        103.0        319.0        500.0                                :
           : T)                          525.0( 54.1) 544.0( 44.4)                              :
           : M)                                                                                 :
   54      :        150.0        171.0                                                          :
           : T)                                                                                 :
           : M)                                                                                 :
   70      :        234.0        317.0                                                          :
           : T) 322.0( 83.6) 432.0( 77.8)                                                       :
           : M)                                                                                 :
   90      :        375.0                                                                       :
           : T)                                                                                 :
           : M)                                                                                 :
           -------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 546.0(101.0) 720.0( 88.9) 671.0( 61.0) 668.0( 50.4) 690.0( 36.2) 974.0(  4.2)
```

TABLE 85

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.10

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.8	6.4	16.4	50.9	474.0
2	2.7	3.7	8.8	22.9	71.0	666.0
3	3.6	4.6	11.0	28.8	86.7	813.0
4	4.5	5.6	13.4	34.8	102.0	934.0
5	5.6	6.6	15.9	41.0	116.0	
7	8.1	8.7	21.4	53.8	144.0	
9	10.9	11.2	28.0	68.1	172.0	
12	15.7	15.3	39.9	91.7	217.0	
15	21.1	20.4	54.1	118.0	263.0	
20	31.8	30.3	84.4	170.0	347.0	
25	44.3	42.2	123.0	229.0	438.0	
33	67.6	66.7	199.0	342.0	601.0	
42	99.6	102.0	311.0	492.0		
54	151.0	164.0	501.0	737.0		
70	234.0	278.0				
90	363.0	481.0				
115	563.0					
DIL AT MAX REAL OR PERMITTED RISE	620.0(121.0)	730.0(108.0)	795.0(68.6)	794.0(56.6)	787.0(41.2)	974.0(4.4)

TABLE 86

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.05

```
                                   DENSIMETRIC FROUDE NUMBER

                            1             3            10            30           100          1000
RISE(DIA)     ------------------------------------------------------------------------------------------
              : T)                                                                      364.0(  0.9)  :
              : M)                                                                                    :
    1         :          1.9           2.8           5.9          13.7          40.5      407.0       :
              : T)                                                                                    :
              : M)                                                                                    :
    2         :          2.7           3.6           7.6          18.6          56.8                  :
              : T)                                                                                    :
              : M)                                                                                    :
    3         :          3.6           4.4           9.1          22.5          71.0                  :
              : T)                                                            81.5(  3.8)             :
              : M)                                                                                    :
    4         :          4.6           5.1          10.3          26.2          84.4                  :
              : T)                                                                                    :
              : M)                                                                                    :
    5         :          5.6           6.0          11.7          29.8         100.0                  :
              : T)                                                                                    :
              : M)                                                                                    :
    7         :          8.1           7.6          14.3          37.8                                :
              : T)                                             41.3(  7.8)                            :
              : M)                                                                                    :
    9         :         10.8           9.4          17.3          46.8                                :
              : T)                                                                                    :
              : M)                                                                                    :
   12         :         15.4          12.3          22.3                                              :
              : T)                                26.0( 13.8)                                         :
              : M)                                                                                    :
   15         :         20.3          15.5          29.0                                              :
              : T)  24.9( 17.7)  20.5( 19.2)                                                          :
              : M)                                                                                    :
   20         :         29.3          21.7                                                            :
              : T)                                                                                    :
              : M)                                                                                    :
   25         :                       30.9                                                            :
              : T)                                                                                    :
              : M)                                                                                    :
              ------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  56.5( 23.9)  46.2( 26.4)  48.9( 19.4)  66.7( 11.6) 127.0(  5.8) 571.0(  1.3)
```

TABLE 87

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.05

```
                                DENSIMETRIC FROUDE NUMBER

                    1              3              10             30             100            1000
RISE(DIA)   ----------------------------------------------------------------------------------------------
            : T)                                                                                          :
            : M)                                                                                          :
    1       :       1.9            2.8            5.9           13.7           40.2           374.0       :
            : T)                                                                          491.0(  1.6)    :
            : M)                                                                                          :
    2       :       2.7            3.6            7.6           18.5           56.1           583.0       :
            : T)                                                                                          :
            : M)                                                                                          :
    3       :       3.6            4.4            9.0           22.3           68.5                       :
            : T)                                                                                          :
            : M)                                                                                          :
    4       :       4.6            5.1           10.3           25.8           79.8                       :
            : T)                                                                                          :
            : M)                                                                                          :
    5       :       5.7            6.0           11.6           29.4           90.4                       :
            : T)                                                             112.0(  7.0)                 :
            : M)                                                                                          :
    7       :       8.1            7.6           14.2           36.5                                      :
            : T)                                                                                          :
            : M)                                                                                          :
    9       :      10.9            9.4           16.9           44.3          137.0                       :
            : T)                                                                                          :
            : M)                                                                                          :
   12       :      15.5           12.3           21.4           57.2                                      :
            : T)                                               65.8( 13.7)                                :
            : M)                                                                                          :
   15       :      20.8           15.6           26.5           73.0                                      :
            : T)                                                                                          :
            : M)                                                                                          :
   20       :      30.7           21.6           37.3                                                     :
            : T)                                45.2( 22.8)                                               :
            : M)                                                                                          :
   25       :      41.3           28.6           53.1                                                     :
            : T)  44.0( 26.2)    36.2( 29.9)                                                              :
            : M)                                                                                          :
   33       :      59.6           42.2                                                                    :
            : T)                                                                                          :
            : M)                                                                                          :
            ----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 109.0( 35.1)  91.4( 39.9)  90.9( 30.5) 108.0( 19.5) 176.0( 10.6) 770.0(  2.4)
```

TABLE 88

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.05

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.8	5.9	13.7	39.9	364.0
2	2.7	3.6	7.6	18.5	55.7	519.0
3	3.6	4.4	9.0	22.2	67.6	647.0
4	4.6	5.1	10.3	25.6	78.2	770.0 774.0(4.1)
5	5.7	6.0	11.6	29.0	88.0	906.0
7	8.1	7.6	14.1	36.0	107.0	
9	10.9	9.4	16.7	43.4	126.0	
12	15.6	12.3	21.0	55.3	155.0	
15	21.0	15.6	25.8	68.5	186.0 205.0(16.6)	
20	31.3	21.7	35.0	94.9	244.0	
25	43.1	28.6	45.9	125.0 150.0(28.5)		
33	64.4	41.6	69.0	187.0		
42	91.1 105.0(46.4)	58.9	108.0 117.0(43.7)			
54	130.0	87.4 88.6(54.6)	214.0			
70		208.0				
DIL AT MAX REAL OR PERMITTED RISE	285.0(61.1)	245.0(70.5)	236.0(55.4)	247.0(38.5)	324.0(24.4)	914.0(5.1)

TABLE 89

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.05

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.8	5.9	13.7	39.9	362.0
2	2.7	3.6	7.6	18.5	55.3	508.0
3	3.6	4.4	9.0	22.2	67.1	621.0
4	4.6	5.1	10.3	25.6	77.6	719.0
5	5.7	6.0	11.6	29.0	87.3	807.0
7	8.1	7.6	14.0	36.0	106.0	
9	10.9	9.4	16.7	43.1	124.0	
12	15.7	12.3	21.0	54.9	152.0	
15	21.0	15.6	25.6	67.6	180.0	
20	31.3	21.7	34.5	92.3	230.0	
25	43.1	28.8	44.9	122.0	285.0	
33	65.3	41.6	65.3	177.0	382.0 T) 486.0(40.6)	
42	94.3	58.8	94.9	254.0	506.0	
54	139.0	86.2	148.0	379.0 T) 426.0(57.9)		
70	205.0 T) 285.0(87.2)	131.0	256.0 T) 374.0(81.7)			
90	299.0	201.0 T) 258.0(103.0)	492.0			
115		332.0				
DIL AT MAX REAL OR PERMITTED RISE	410.0(109.0)	558.0(127.0)	602.0(96.1)	577.0(69.0)	598.0(48.0)	914.0(6.4)

TABLE 90

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.05

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.8	5.9	13.7	39.9	362.0
2	2.7	3.6	7.6	18.5	55.3	508.0
3	3.6	4.4	9.0	22.2	67.1	617.0
4	4.6	5.1	10.3	25.6	77.6	710.0
5	5.7	6.0	11.6	29.0	87.3	791.0
7	8.1	7.6	14.0	36.0	105.0	
9	10.9	9.4	16.7	43.1	124.0	
12	15.7	12.3	21.0	54.5	151.0	
15	21.1	15.6	25.4	67.6	180.0	
20	31.5	21.7	34.3	92.3	229.0	
25	43.4	28.8	44.6	121.0	282.0	
33	65.7	41.9	64.4	175.0	376.0	
42	94.9	59.3	92.3	249.0	493.0	
54	141.0	86.1	141.0	367.0	670.0	
70	212.0	131.0	227.0	564.0		
90	317.0	199.0	379.0			
115	470.0	302.0	637.0			
148		476.0				
DIL AT MAX REAL OR PERMITTED RISE	571.0(130.0)	551.0(160.0)	689.0(119.0)	717.0(80.7)	708.0(56.5)	914.0(6.7)

TABLE 91

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.02

```
                                 DENSIMETRIC FROUDE NUMBER

                       1           3           10          30          100         1000
RISE(DIA)  --------------------------------------------------------------------------------
           : T)                                                                           :
           : M)                                                                           :
    1      :          1.9         2.7         5.5         11.9        30.5        265.0   :
           : T)                                                                282.0(  1.1) :
           : M)                                                                           :
    2      :          2.7         3.6         7.1         15.5        41.6                :
           : T)                                                                           :
           : M)                                                                           :
    3      :          3.6         4.3         8.2         18.2        50.5                :
           : T)                                                                           :
           : M)                                                                           :
    4      :          4.6         5.1         9.3         20.5        58.4                :
           : T)                                                    64.0(  4.7)            :
           : M)                                                                           :
    5      :          5.7         5.9         10.2        22.6        66.7                :
           : T)                                                                           :
           : M)                                                                           :
    7      :          8.1         7.5         12.0        26.5        89.8                :
           : T)                                                                           :
           : M)                                                                           :
    9      :          10.8        9.2         13.7        30.5                            :
           : T)                                        31.5(  9.5)                        :
           : M)                                                                           :
   12      :          15.2        12.0        16.2        37.5                            :
           : T)                                                                           :
           : M)                                                                           :
   15      :          20.3        14.9        19.0                                        :
           : T)  24.8( 17.6)  19.7( 19.6)  19.8( 16.0)                                    :
           : M)                                                                           :
   20      :          29.0        20.1        24.4                                        :
           : T)                                                                           :
           : M)                                                                           :
   25      :                      25.6                                                    :
           : T)                                                                           :
           : M)                                                                           :
           --------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  45.8( 24.0)  34.8( 27.6)  33.5( 23.8)  49.2( 14.5)  99.7(  7.2) 439.0(  1.7)
```

TABLE 92

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.02

```
                                 DENSIMETRIC FROUDE NUMBER

                     1             3            10            30           100          1000
RISE(DIA)  ------------------------------------------------------------------------------------
           : T)                                                                               :
           : M)                                                                               :
    1      :        1.9           2.7           5.5          11.9          30.5         254.0 :
           : T)                                                                               :
           : M)                                                                               :
    2      :        2.7           3.6           7.1          15.5          41.0         374.0 :
           : T)                                                                      380.0(  2.1) :
           : M)                                                                               :
    3      :        3.6           4.3           8.2          18.1          49.1         528.0 :
           : T)                                                                               :
           : M)                                                                               :
    4      :        4.6           5.1           9.3          20.4          56.5               :
           : T)                                                                               :
           : M)                                                                               :
    5      :        5.7           5.9          10.2          22.3          63.1               :
           : T)                                                                               :
           : M)                                                                               :
    7      :        8.1           7.5          11.9          25.8          75.0               :
           : T)                                                        86.2(  8.9)             :
           : M)                                                                               :
    9      :       10.9           9.2          13.5          29.2          87.4               :
           : T)                                                                               :
           : M)                                                                               :
   12      :       15.5          12.0          16.0          34.3         109.0               :
           : T)                                                                               :
           : M)                                                                               :
   15      :       20.7          15.1          18.5          39.6                             :
           : T)                                         44.9( 17.7)                           :
           : M)                                                                               :
   20      :       30.5          20.7          22.9          50.2                             :
           : T)                                                                               :
           : M)                                                                               :
   25      :       41.3          26.9          27.9          65.8                             :
           : T)  43.7( 26.2)  34.1( 30.7)  30.9( 28.1)                                        :
           : M)                                                                               :
   33      :       58.4          37.3          37.0                                           :
           : T)                                                                               :
           : M)                                                                               :
   42      :                     58.3                                                         :
           : T)                                                                               :
           : M)                                                                               :
           ------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE  90.6( 35.3)  67.9( 42.1)  59.1( 40.2)  74.4( 26.3) 135.0( 13.5) 594.0(  3.1)
```

TABLE 93

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.02

```
                                    DENSIMETRIC FROUDE NUMBER
                        1              3             10             30            100           1000
RISE(DIA)    ----------------------------------------------------------------------------------------------
             : T)                                                                                          :
             : M)                                                                                          :
     1       :        1.9            2.7            5.5           11.9           30.5          249.0       :
             : T)                                                                                          :
             : M)                                                                                          :
     2       :        2.7            3.6            7.1           15.3           40.8          352.0       :
             : T)                                                                                          :
             : M)                                                                                          :
     3       :        3.6            4.3            8.2           18.0           48.8          433.0       :
             : T)                                                                                          :
             : M)                                                                                          :
     4       :        4.6            5.1            9.3           20.2           55.7          508.0       :
             : T)                                                                                          :
             : M)                                                                                          :
     5       :        5.7            5.9           10.1           22.2           61.3          578.0       :
             : T)                                                                            594.0(  5.2)  :
             : M)                                                                                          :
     7       :        8.1            7.5           11.9           25.6           71.9          744.0       :
             : T)                                                                                          :
             : M)                                                                                          :
     9       :       10.9            9.2           13.5           28.8           82.1                      :
             : T)                                                                                          :
             : M)                                                                                          :
    12       :       15.6           12.0           15.9           33.3           96.3                      :
             : T)                                                                                          :
             : M)                                                                                          :
    15       :       21.0           15.1           18.4           38.0          111.0                      :
             : T)                                                                                          :
             : M)                                                                                          :
    20       :       31.1           21.0           22.6           46.2          137.0                      :
             : T)                                                             149.0( 22.2)                 :
             : M)                                                                                          :
    25       :       42.8           27.5           27.3           54.9          166.0                      :
             : T)                                                                                          :
             : M)                                                                                          :
    33       :       64.0           38.8           35.2           71.0                                     :
             : T)                                               91.7( 41.1)                                :
             : M)                                                                                          :
    42       :       90.4           53.4           45.5           94.9                                     :
             : T) 104.0( 46.4)                                                                             :
             : M)                                                                                          :
    54       :      127.0           74.5           60.9          147.0                                     :
             : T)                 79.8( 57.0)     69.0( 59.5)                                              :
             : M)                                                                                          :
    70       :                     105.0           89.2                                                    :
             : T)                                                                                          :
             : M)                                                                                          :
             ----------------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 251.0( 61.6) 190.0( 76.4) 160.0( 80.1) 170.0( 56.8) 238.0( 32.7) 807.0(  7.5)
```

TABLE 94

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.02

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.7	5.5	11.9	30.5	249.0
2	2.7	3.6	7.1	15.3	40.8	347.0
3	3.6	4.3	8.2	18.0	48.8	421.0
4	4.6	5.1	9.3	20.2	55.3	487.0
5	5.7	5.9	10.1	22.2	60.9	545.0
7	8.1	7.5	11.9	25.4	71.4	644.0
9	10.9	9.2	13.5	28.6	80.9	735.0
12	15.6	12.0	15.9	33.1	94.9	
15	21.0	15.2	18.4	37.5	108.0	
20	31.3	21.0	22.6	45.2	131.0	
25	43.4	27.5	27.1	53.4	156.0	
33	65.3	39.4	35.2	67.6	199.0	
42	94.3	54.5	45.2	86.1	252.0	
54	138.0	77.6	60.1	115.0	334.0 347.0(55.8)	
70	204.0 282.0(87.2)	112.0	83.2	165.0	466.0	
90	295.0	162.0 216.0(110.0)	118.0	257.0 264.0(91.5)		
115		229.0	171.0 193.0(124.0)	461.0		
148			293.0			
DIL AT MAX REAL OR PERMITTED RISE	384.0(110.0)	337.0(144.0)	470.0(158.0)	467.0(116.0)	478.0(71.3)	807.0(10.7)

TABLE 95

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.02

	DENSIMETRIC FROUDE NUMBER					
RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.7	5.5	11.9	30.5	249.0
2	2.7	3.6	7.1	15.3	40.8	347.0
3	3.6	4.3	8.2	18.0	48.5	421.0
4	4.6	5.1	9.3	20.2	55.3	484.0
5	5.7	5.9	10.1	22.2	60.9	539.0
7	8.1	7.5	11.9	25.4	71.4	632.0
9	10.9	9.2	13.5	28.6	80.9	712.0
12	15.7	12.0	15.9	33.1	94.3	
15	21.0	15.2	18.2	37.5	108.0	
20	31.3	21.1	22.6	45.2	131.0	
25	43.4	27.7	27.1	53.0	154.0	
33	65.7	39.4	35.0	66.7	195.0	
42	94.9	54.9	45.2	84.4	245.0	
54	140.0	78.2	60.1	111.0	320.0	
70	211.0	114.0	83.2	154.0	435.0	
90	316.0	167.0	117.0	221.0		
115	468.0	243.0	166.0	328.0		
148		360.0	247.0	512.0		
190			371.0			
DIL AT MAX REAL OR PERMITTED RISE	570.0(130.0)	486.0(179.0)	460.0(216.0)	565.0(156.0)	598.0(89.6)	807.0(11.7)

TABLE 96

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 200
CURRENT TO EFFLUENT RATIO = 0.00

RISE(DIA)	DENSIMETRIC FROUDE NUMBER 1	3	10	30	100	1000
1	1.9	2.7	5.3	10.6	23.6	111.0 144.0(2.0)
2	2.7	3.5	6.7	13.5	29.8	146.0
3	3.6	4.3	7.8	15.5	34.5	167.0
4	4.6	5.0	8.7	17.1	38.6	
5	5.7	5.8	9.6	18.6	41.9 45.5(6.1)	
7	8.1	7.4	11.2	21.3	48.8	
9	10.8	9.1	12.7	23.7 26.0(11.0)	56.9	
12	15.2	11.8	14.9	27.3		
15	20.3 24.8(17.7)	14.7 19.6(19.8)	17.3 18.5(16.8)	30.9		
20	28.8	19.8	21.0			
25		24.9	25.0			
DIL AT MAX REAL OR PERMITTED RISE	34.9(24.0)	27.5(27.8)	26.1(25.6)	36.6(17.3)	64.3(9.8)	203.0(3.1)

TABLE 97

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 500
CURRENT TO EFFLUENT RATIO = 0.00

```
                                       DENSIMETRIC FROUDE NUMBER

                         1             3            10            30           100          1000
  RISE(DIA)   ---------------------------------------------------------------------------------------
              : T)                                                                                  :
              : M)                                                                                  :
      1       :        1.9           2.7          5.3          10.6         23.6        110.0       :
              : T)                                                                                  :
              : M)                                                                                  :
      2       :        2.7           3.5          6.7          13.4         29.6        140.0       :
              : T)                                                                                  :
              : M)                                                                                  :
      3       :        3.6           4.3          7.7          15.5         34.0        163.0       :
              : T)                                                                    181.0(  3.9)  :
              : M)                                                                                  :
      4       :        4.6           5.0          8.7          17.0         37.8        185.0       :
              : T)                                                                                  :
              : M)                                                                                  :
      5       :        5.7           5.8          9.5          18.5         40.8        206.0       :
              : T)                                                                                  :
              : M)                                                                                  :
      7       :        8.1           7.4         11.2          21.0         46.2                    :
              : T)                                                                                  :
              : M)                                                                                  :
      9       :       10.9           9.1         12.6          23.1         50.9                    :
              : T)                                                     57.6( 12.1)                :
              : M)                                                                                  :
     12       :       15.5          11.9         14.9          26.2                                 :
              : T)                                                                                  :
              : M)                                                                                  :
     15       :       20.7          14.9         17.1          28.8         64.4                    :
              : T)                                                                                  :
              : M)                                                                                  :
     20       :       30.5          20.5         21.0          33.3                                 :
              : T)                                          34.3( 21.3)                             :
              : M)                                                                                  :
     25       :       41.1          26.5         24.8          37.8                                 :
              : T)  43.7( 26.2)  33.8( 30.9)   28.4( 29.7)                                          :
              : M)                                                                                  :
     33       :       58.0          36.8         31.1          46.7                                 :
              : T)                                                                                  :
              : M)                                                                                  :
     42       :                     47.0         38.1                                               :
              : T)                                                                                  :
              : M)                                                                                  :
              ---------------------------------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE   61.6( 35.3)  47.5( 42.6)   40.0( 43.9)  48.2( 33.3)  81.1( 19.4) 255.0(  6.2)
```

TABLE 98

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 2000
CURRENT TO EFFLUENT RATIO = 0.00

```
                                   DENSIMETRIC FROUDE NUMBER

                           1           3          10          30         100        1000
RISE(DIA)     ---------------------------------------------------------------------------
          : T)                                                                           :
          : M)                                                                           :
   1      :              1.9         2.7         5.3        10.6        23.4       109.0 :
          : T)                                                                           :
          : M)                                                                           :
   2      :              2.7         3.5         6.7        13.4        29.6       138.0 :
          : T)                                                                           :
          : M)                                                                           :
   3      :              3.6         4.3         7.7        15.3        34.0       159.0 :
          : T)                                                                           :
          : M)                                                                           :
   4      :              4.6         5.0         8.7        17.0        37.5       175.0 :
          : T)                                                                           :
          : M)                                                                           :
   5      :              5.7         5.8         9.5        18.4        40.5       190.0 :
          : T)                                                                           :
          : M)                                                                           :
   7      :              8.1         7.4        11.1        20.8        45.2       213.0 :
          : T)                                                                           :
          : M)                                                                           :
   9      :             10.9         9.1        12.6        22.9        49.5       236.0 :
          : T)                                                                255.0( 10.8) :
          : M)                                                                           :
  12      :             15.6        12.0        14.8        25.8        54.9       267.0 :
          : T)                                                                           :
          : M)                                                                           :
  15      :             21.0        15.0        17.1        28.4        59.7       302.0 :
          : T)                                                                           :
          : M)                                                                           :
  20      :             31.1        20.8        21.0        32.4        66.6             :
          : T)                                                                           :
          : M)                                                                           :
  25      :             42.8        27.1        25.1        36.2        73.1             :
          : T)                                                                           :
          : M)                                                                           :
  33      :             64.0        38.6        31.8        42.2        82.8             :
          : T)                                                       83.6( 33.8)           :
          : M)                                                                           :
  42      :             90.4        53.0        40.2        49.1        93.8             :
          : T) 104.0( 46.4)                              57.8( 54.1)                       :
          : M)                                                                           :
  54      :            127.0        74.0        52.0                                     :
          : T)                   79.3( 57.3) 60.9( 63.3)                                   :
          : M)                                                                           :
  70      :                        102.0        68.1        69.8                         :
          : T)                                                                           :
          : M)                                                                           :
          ------------------- -------------------------------------------------------------

DIL AT MAX REAL
OR PERMITTED RISE 146.0( 61.7) 111.0( 77.3)  85.8( 89.6)  81.5( 82.4) 117.0( 53.7) 359.0( 17.4)
```

TABLE 99

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = 10000
CURRENT TO EFFLUENT RATIO = 0.00

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.7	5.3	10.6	23.4	109.0
2	2.7	3.5	6.7	13.4	29.6	137.0
3	3.6	4.3	7.7	15.3	33.8	157.0
4	4.6	5.0	8.7	17.0	37.2	173.0
5	5.7	5.8	9.5	18.4	40.2	186.0
7	8.1	7.4	11.1	20.8	45.2	208.0
9	10.9	9.1	12.6	22.9	49.1	228.0
12	15.6	12.0	14.8	25.6	54.5	251.0
15	21.0	15.0	17.1	28.2	58.8	272.0
20	31.3	20.8	21.0	32.2	65.7	302.0
25	43.4	27.3	25.1	36.0	71.2	328.0
33	65.3	39.1	32.0	41.9	79.3	367.0 T) 381.0(36.0)
42	94.3	54.2	40.5	48.8	88.0	
54	138.0	76.6	53.0	58.0	98.3	
70	204.0 T) 282.0(87.3)	111.0	71.4	70.4	112.0	
90	295.0	160.0 T) 215.0(111.0)	96.8	87.0	127.0 T) 139.0(106.0)	
115		226.0	131.0 T) 160.0(135.0)	109.0 T) 130.0(139.0)	147.0	
148			179.0	138.0	173.0	
190				174.0		

DIL AT MAX REAL
OR PERMITTED RISE 381.0(110.0) 298.0(145.0) 225.0(184.0) 183.0(201.0) 187.0(162.0) 407.0(41.5)

TABLE 100

DIFFUSER PLUME DILUTION
PORT SPACING = 1000 DIAMETERS, STABILITY STRATIFICATION PARAMETER = INFINITE
CURRENT TO EFFLUENT RATIO = 0.00

DENSIMETRIC FROUDE NUMBER

RISE(DIA)	1	3	10	30	100	1000
1	1.9	2.7	5.3	10.6	23.4	108.0
2	2.7	3.5	6.7	13.4	29.6	137.0
3	3.6	4.3	7.7	15.3	33.8	156.0
4	4.6	5.0	8.7	17.0	37.2	172.0
5	5.7	5.8	9.5	18.4	40.2	186.0
7	8.1	7.4	11.1	20.8	45.2	208.0
9	10.9	9.1	12.6	22.9	49.1	226.0
12	15.7	12.0	14.8	25.6	54.1	248.0
15	21.0	15.0	17.1	28.2	58.9	268.0
20	31.3	20.8	21.0	32.2	65.3	295.0
25	43.4	27.3	25.1	36.0	70.8	318.0
33	65.7	39.1	32.0	41.9	79.1	348.0
42	94.9	54.1	40.8	48.8	87.2	378.0
54	140.0	77.6	53.4	58.0	97.3	
70	211.0	114.0	71.9	70.5	110.0	
90	315.0	165.0	99.0	87.5	125.0	
115	468.0	242.0	136.0	111.0	143.0	
148		357.0	193.0	144.0	168.0	
190			276.0	191.0	200.0	
244			400.0	259.0	244.0	
DIL AT MAX REAL OR PERMITTED RISE	569.0(130.0)	485.0(180.0)	402.0(245.0)	329.0(294.0)	248.0(250.0)	407.0(52.5)

APPENDIX H

EQUIVALENTS OF COMMONLY USED UNITS OF MEASUREMENT

TABLE H-1

EQUIVALENTS OF COMMONLY USED UNITS OF MEASUREMENT

English Unit	Multiplier	SI Unit	English Unit	Multiplier	SI Unit
acre	X4.046.724→ ← 2.471X10^{-4}X	m^2	gpd/ft	X0.0124→ ← 80.65X	m^3/day m
acre	X0.405→ ← 2.471X	ha*	gpd/sq ft	X0.0408→ ← 24.51X	m^3/day m^2
acre-ft	X1,233.5→ ← 8.11X10^{-4}X	m^3	gpm	X0.0631→ ← 15.85X	dm^3/s
Btu	X1.055→ ← 0.9478X	kJ	gpm	X0.0631→ ← 15.85X	1*/s
Btu	X0.252→ ← 3.968X	kg-cal*	gpm/sq ft	X40.7→ ← 0.0245X	1*/min m^2
Btu/hr/sq ft	X3.158→ ← 0.316X	J/s-m^2	hp	X0.7454→ ← 1.341X	kW
Btu/lb	X0.555→ ← 1.80X	kg-cal/kg*	hp-hr	X2.684→ ← 0.372X	MJ
cfm	X0.028→ ← 35.71X	m^3/min	in.	X2.54→ ← 0.3937X	cm
cfs	X1.7→ ← 0.588X	m^3/min	lb/day/acre-ft	X3.68→ ← 0.2717X	g/day m^3
cfs/sq miles	X0.657→ ← 1.522X	m^3/min km^2	lb/1,000 cu ft	X16.0→ ← 0.0625X	g/m^3
cu ft	X0.028→ ← 35.314X	m^3	lb/day/cu ft	X16→ ← 0.0625X	kg/day m^3
cu ft	X28.32→ ← 0.0353X	1*	lb/mil gal	X0.92→ ← 8.333X	g/m^3
cu in.	X16.39→ ← 0.061X	cm^3	mil gal	X3,785→ ← 2.64X10^{-4}X	m^3
cu yd	X0.75→ ← 1.3709X	m^3	mgd	X3,785→ ← 2.64X10^{-4}X	m^3/day
^{o}F	0.555(^{o}F−32)→ ← 1.8(^{o}C)+32	^{o}C	mgd	X0.0438→ ← 22.82X	m^3/s
^{o}C	plus 273→ ← minus 273	K	mile	X1.61→ ← 0.621X	km
ft	X0.3048→ ← 3.28X	m	ppb	X10^{-3}→ ← 1,000X	mg/1*
ft-1b	X1.356→ ← 0.737X	J	ppm	approximately equal to	mg/1*
gal	X3.785→ ← 0.264X	1*	sq ft	X0.0929→ ← 10.76X	m^2
gal	X0.003785→ ← 264.2X	m^3	sq in.	X645.2→ ← 0.00155	mm^2
gpd/acre	X0.9365→ ← 1.068X	m^3/day km^2	sq miles	X2.590→ ← 0.3861X	km^2

Other commonly used conversions:

1 MGD = 1.55cfs

1 MW = 3.414 X 10^6 BTU/hr

1 BTU = 252 cal

γc_p = 62.4 BTU/ft^3/^{o}F

1 BTU = 778 ft-1b

1 Langley/day = 3.7 BTU/ft.^{2}/day

*Not an SI unit, but a term commonly used and preferred as a wastewater unit of expression.